ASSESSING WATERHOLE DESIGN AND DETERMINING THE IMPACT OF ARTIFICIAL WATERHOLES IN BALULE NATURE RESERVE, SOUTH AFRICA

by

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Declaration

I declare that **ASSESSING WATERHOLE DESIGN AND DETERMINING THE IMPACT OF ARTIFICIAL WATERHOLES IN BALULE NATURE RESERVE, SOUTH AFRICA** is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

26/01/2016

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Eilidh Smith Date

Summary

Herbivores have a significant influence on their environment. Factors that influence herbivore distribution in a landscape are important for conservation. Artificial water provision is one such factor, with water sources being focal points of herbivore activity. Variation between herbivore utilisation of different waterhole types and habitat integrity surrounding the different waterholes is assessed in this study. Correlations are drawn between herbivore utilisation and habitat integrity to quantify the impact that artificial waterholes have on the landscape. A scoring system is devised to investigate the various factors affecting vegetation around artificial waterholes. Results show that there are significant variations between herbivore utilisation for different artificial waterhole types, as well as significant variation in habitat integrity surrounding the different waterhole types. Distance between waterholes and drainage lines, and utilisation by specific herbivore species have a significant impact on habitat integrity - specifically affecting veld condition and disturbance observed on woody plant species. A habitat score that was created by combining data from both the herbaceous and woody layers is not affected by waterhole type, distance from waterholes, or the different herbivore species utilising the different waterhole types. Earth dams have the greatest impact on surrounding vegetation and are the most utilised waterhole type. Closures of earth dams are not recommended due to their importance to herbivores. Less utilised waterhole types are also important, mitigating the impact of herbivore damage to vegetation at earth dams.

Key Terms

Artificial waterhole, Balule, habitat integrity, herbaceous layer, herbivore impact, piosphere, woody layer

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Chapter 1 : Introduction

1.1: Background

The provision of artificial water points in nature reserves in Southern Africa has been described as detrimental to ecosystem health (Owen-Smith 1996; Thrash 1998; Thrash 2000). Water requirements influence the movement patterns of herbivores (Redfern *et. al.* 2003; Redfern *et. al.* 2005; Grant & Smit 2009; Matthews *et. al.* 2009), which in turn influences vegetation composition around water sources (Owen-Smith 1996; Thrash 1998; Thrash 2000; Smit *et. al.* 2007; Winnie *et. al.* 2008; Matthews *et. al.* 2009). Understanding how artificial water points influence the landscape and biodiversity are important for managing reserves.

Research on the effects of artificial water points often investigate gradients of disturbance to vegetation surrounding waterholes, with results indicating that disturbance decreases with increasing distance from water. With this in mind, the consequences of an over-abundance of water points can reduce biodiversity and ecosystem resilience to disturbance and drought if there is not enough distance between waterholes (Smit *et. al.* 2007).

A reduction of biodiversity in the vicinity of artificial waterholes is attributed to the over-abundance of water sources that affects both the plant communities and herbivores (Thrash 2000; Grant & Smit 2009). It has been suggested that an increase in surface water availability leads to an increase in water-dependent competitive grazers, with forage and not water, being the limiting factor during the dry season (Smit *et. al.* 2007; Grant & Smit 2009). Increased numbers of grazers result in extensive over-grazing of areas leading to the homogenisation of vegetation (Thrash *et. al.* 1995; Grant & Smit 2009). The loss of landscape heterogeneity has been implicated in the loss of herbivore biodiversity, for example, the decline of species such as roan and sable antelope (*Hippotragus equinus*) and (*Hippotragus niger*), that rely on patches of refugia that lie out of reach of the more water-dependent competitive grazers (Pienaar 1998; Harrington *et. al.* 1999). In addition to this, an increase in prey species populations is implicated in the growth of predator populations

such as lion (*Panthera leo*), resulting in greater predation pressure on already declining species like the roan antelope in areas where they coexist (Harrington *et. al.* 1999; Knoop & Owen-Smith 2006).

Loss of biodiversity is not the only consequence when considering the over-grazing that results from increased grazer populations. A general decline in vegetated areas may be observed, resulting in a reduction of the larger ecosystem resilience, particularly in times of drought (Owen-Smith 1996). High water-density has been implicated as the reason that areas such as Klaserie and Umfolozi experienced high levels of herbivore and grass tuft mortality during a two-year drought in the early eighties (Walker *et. al.* 1987). Due to the close-spacing of waterholes, extensive over-grazing caused by high stocking-rates of herbivores there was not enough forage, and local populations of some herbivores were decimated (Walker *et. al.* 1987; Owen-Smith 1996).

The same drought caused fatalities in the Kruger National Park (KNP), however, these were not as extensive as those observed in the private nature reserves of Greater Kruger, Klaserie and Umfolozi (Walker *et. al.* 1987). Fatalities were attributed to differences in spacing between waterholes in the aforementioned areas (Owen-Smith 1996). For example, in Klaserie there was an average distance between waterholes of 2 km, while in central KNP, the average distance between waterholes was greater than 10 km (Owen-Smith 1996). In 1997, the KNP increased the average distance between waterholes across the whole park in response to growing evidence of the detrimental effects of excess water provision (Grant & Smit 2009). This was done in light of suggestions that fewer water sources cause considerable damage to vegetation due to a concentration of animals around waterholes (Redfern *et. al.* 2005), and that more sensitive species with narrow habitat ranges would have to travel further to find water thereby lessening the impact on the vegetation (Grant & Smit 2009). This approach favoured the more concentrated impact of over-grazing and trampling at fewer waterholes (Thrash *et. al.* 1995; Gaylard 1998), rather than mitigating this impact by spreading it out over many waterholes. This was demonstrated by Gaylard (1998) who monitored elephant behaviour and surveyed vegetation damage in the Kruger National Park. Gaylards' study found waterhole frequency to have a widespread impact on vegetation, suggesting that the removal of waterholes will force elephants to concentrate

on fewer areas resulting in relief areas for impact-intolerant species. In addition, Grant & Smit (2009) found that while the scheme of closing waterholes initially seemed successful, populations of roan continued to decline.

Not all of the literature is in agreement on the extent of the influence of artificial water points on plant communities and habitat integrity. Smit (1998) suggests that there is no evidence for elephants using artificial waterholes in the dry season, and that the removal of waterholes is more likely to harm non-target species, rather than regulating the impact of elephants in areas where they are perceived to have a wide-spread impact facilitated by additional waterholes. Further to this, Nangula & Oba (2004) attribute variation in vegetation more to changes in landscape type, than to association with water. Similarly, the impact of artificial waterholes may be dependent on herbivore stocking rates (Thrash 2000), with artificial waterholes having less impact on habitat integrity in less populated areas.

With this in mind, further investigations are suggested, particularly to investigate variations in herbivore utilisation, habitat assessment in terms of distance from waterholes, and variations with regard to waterhole design and herbivore selection of waterholes.

1.2 Herbivore Utilisation of waterholes

Availability of water affects herbivore populations and their movement patterns (Owen-Smith, 1996). It is important to understand how waterholes are utilised to determine the impact that they have on habitat integrity. Herbivore utilisation of artificial waterholes may be affected by waterhole design, as some artificial waterholes have high sides that favour only large species such as elephant. Waterholes may also vary in size or include mud wallows, which are valuable to species like warthog and rhino (Waldram *et. al.* 2008; Vanschoenwinkel 2011; Dunkin *et. al.* 2013). Additional factors that may affect herbivore utilisation of waterholes include perceived predation risk (Fischoff *et. al.* 2007; Davidson *et. al.* 2010; Crosmary *et. al.* 2011), avoidance of interspecies competition (Valeix *et. al.* 2007; Hayward & Hayward 2012), the behavioural patterns of species i.e. time of peak activity (Mukinya 1977; Hayward & Hayward 2012) and gregariousness (Morrell *et. al.* 2011).

Seasonal variation occurs as surface-water availability diminishes during the dry season, and herbivores become more dependent on artificial water sources (Smit *et. al.* 2007; Hayward & Hayward 2012).

1.3 The impact of artificial waterholes on habitat integrity

By influencing the movement patterns of herbivores, artificial waterholes have the potential to significantly influence habitat integrity across the landscape (Smit *et. al.* 2007). Smit *et. al.* (2007) suggests that a gradient of influence exists in a five kilometre zone surrounding waterholes, caused by increased herbivore traffic resulting in increased grazing and browsing pressure accompanied by trampling.

Zambatis (2003) suggests that the primary influence on the herbaceous layer is rainfall, with distance to permanent drinking water, and competition from the woody layer only having secondary influences. Direct herbivore utilisation is reported to have only limited impact on the herbaceous layer, which may be exaggerated by soil moisture stress above a certain threshold (Zambatis 2003). Vulnerable woody species seedlings are affected by the trampling effect of wildlife traffic (Chamaillé-Jammes *et. al.* 2009).

1.4 Assessing the influence of habitat integrity for selected herbivores

Variation in species composition and species population dynamics of herbivores utilising different waterhole types may lead to variation in the impact an artificial waterhole has on habitat integrity (Grange & Duncan 2006). Different species of herbivores have different levels of impact on vegetation, for example elephants and impala are thought to be particularly influential (Bergström 1992; Midgley *et. al.* 2010), with elephants being capable of killing trees through bark-stripping or felling (Jacobs & Biggs 2002), while high numbers of impala reduce seedling recruitment (O'Kane *et. al.* 2012). Similarly, whether a species is a bulk feeder or a selective feeder may affect the influence it has on vegetation, for example, bulk feeders have a high impact on seedlings by consuming them whilst grazing (Midgely *et.*

al. 2010). Herbivore impact is also significantly related to the effect of trampling (Thrash 2000; Smit *et. al.* 2007; Chamaillé-Jammes *et. al.* 2009) and frequency of visits to a waterhole by individuals of a particular species may affect the proportional influence they have on the vegetation surrounding the waterhole (Smit *et. al.* 2007). Size of herbivore also causes variation in influence, with larger herbivore species causing greater disturbances due to heavier footfall (Shankar & Singh 1996; Cumming & Cumming 2003). In addition to this, group size also affects a species' influence on vegetation around waterholes, especially if group size is too large to stick to established game trails, resulting in excessive trampling.

1.5 Objectives

Olifants West Nature Reserve, in which this research was conducted, has an abundance of artificial waterholes with an average distance between waterholes of less than the recommended 10 km (Thrash *et. al.* 1995). Utilisation patterns of herbivores were identified to determine the intrinsic value of artificial waterholes for providing water, and to establish if relationships exist between habitat integrity and specific herbivore utilisation patterns. Impact on vegetation surrounding waterholes was defined in terms of veld condition score, biodiversity of woody species, height of woody species and levels of perceived disturbance to woody species.

The following objectives were identified for the research:

1. To establish herbivore utilisation patterns and impact on surrounding habitat for artificial waterholes: pans, reservoirs and earth dams.
2. To determine habitat integrity, using a scoring mechanism developed for this study, which includes data from both the herbaceous and woody layers of vegetation surrounding artificial waterholes, with emphasis on distance from water and variation between waterhole types.
3. To investigate relationships between herbivore utilisation and habitat integrity to establish the relative impact of different artificial waterhole types on habitat integrity using variations in herbivore utilisation patterns as explanatory factors.

It was hypothesised that:

1. Significant variations would occur between artificial waterhole types and herbivore utilisation due to variations in water volume and height of waterhole sides, which could prevent smaller herbivores from accessing certain waterholes.
2. Significant variation in herbivore species utilisation patterns was also expected since previous research indicates that species vary in their times of utilisation, for example Valeix *et. al.* (2007) found most herbivores to be diurnal except for elephants, whose waterhole use peaked at dusk. Hayward & Hayward (2012) found that predators utilised water predominantly after dusk or before dawn.
3. Further variation between frequencies of utilisation was expected due to differences in water dependency (Hayward & Hayward 2009).
4. Variation in habitat integrity was expected in relation to distance from water, as per piosphere theory (Thrash 2000), with veld condition, woody species diversity, and woody species height predicted to decrease closer to waterholes.
5. Level of disturbance to woody species was expected to be higher closer to waterholes.
6. It was expected that there would be significant relationships between certain herbivores and elements of habitat integrity, as different herbivores have varying levels of impact on vegetation (Shankar & Singh 1996; Bergström 1992; Cumming & Cumming 2003; Midgely *et. al.* 2010).

This dissertation contains three data chapters: the first analyses and discusses herbivore utilisation of waterholes using data collected from camera trap observations of nine artificial waterholes; the second data chapter focuses on the vegetation component, analysing and discussing data collected from vegetation surveys of both the herbaceous and woody layers in the vicinity of the nine study waterholes; and the third and final data chapter combines the results of the previous two chapters and draws conclusions on the relationship herbivores have with the vegetation surrounding waterholes. The chapters are all written in publication format, hence the introduction and methods sections are somewhat repetitive of the methodology chapter.

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Chapter 2 : Study Area

2.1 Location and size

The study site is situated within Balule Private Nature Reserve and consists of 8,800 hectares that make up the Olifants West Nature Reserve (OWNR) (Coordinates: -24.1987, 30.9090) (Figure 2.1).

Figure 2.1: Map showing the position of the study site, Olifants West Nature Reserve, in relation to the rest of South Africa. Olifants West Nature Reserve is labelled and indicated by the yellow pin (Google Earth).

Balule Nature Reserve, including the study site Olifants West, is part of the Associated Private Nature Reserves (APNR), which is a collection of privately owned reserves (36,327 ha in size), with no boundary fences between the reserves or with the adjoining Kruger National Park.

2.2 Topography and geology

The altitude of the APNR ranges from 440 – 520 meters above sea level (m.a.s.l). Altitude of the study area ranges from 338 m.a.s.l in the east to 360 m.a.s.l in the west. The study site is considered arid savannah (Peel 2007) with granitoid based geology of the Swazian and Randian age group, derived from the Basement complex (Venter 1990).

2.3 Soil

In the Savannah biome there is a significant relationship between soil type and vegetation communities present (Mucina & Rutherford 2006). The soil type in the study area is granitic-derived (Kos *et. al.* 2012), related to the underlying geology of the area (Venter 1990). Soil in the APNR, in which the study site is found, has also been described as gabbro-derived (Kos *et. al.* 2012). Gabbroic soils are, by comparison, more fertile than granitic soils, which are nutrient-poor (Kos *et. al.* 2012).

2.4 Vegetation

The study site is located entirely in the Savannah biome (Mucina & Rutherford 2006) and is categorised as Lowveld, Arid Lowveld and Mopani Veld (Acocks 1998) or Mopani Bushveld, Mixed Lowveld Bushveld, Sweet Lowveld Bushveld (Low & Rebelo 1996). Savannah is characterised by a grass dominated ground layer with an upper woody vegetation layer (Low & Rebelo 1996).

Table 2.1 shows the grass and woody species recorded at the study site. Thirty two species of grasses and 19 woody plant species have been identified during the annual vegetation surveys carried out in the OWNR.

Table 2.1: Grass and woody species identified for the study site

Grass species	**Woody species**
Aristida congesta-barbicolis	*Combretum apiculatum* - Rooibos
Aristida congesta-congesta	*Lannea schweinfurthii* - False marula
Aristida meridionalis	*Sclerocarrya birrea* - Marula
Aristida scabrivalvis	*Commifera* spp. – Corkwood spp.
Aristida transvaalensis	*Grewia* spp. – Raisin bush spp.
Bothriochloa radicans	*Senegalia nigrescens* - Knobthorn
Brachiaria deflexa	*Dichrostachys cinerea* - Sickle bush
Cenchrus ciliarus	*Terminalia prunioides* - Lowveld clusterleaf
Chloris pycnothrix	*Senegalia erubescens* - Bluethorn
Chloris virgata	*Dalbergia melanoxylon* - Zebrawood
Cymbopogon caesius	*Boscia* spp.
Digitaria eriantha	*Balanites maughamii* - Green thorn
Enneapogon cenchroides	*Ehretia amoena* - Sandpaper bush
Eragrostis lehmanniana	*Euclea divinorum* – Magic guarri
Eragrostis patentipilos	*Combretum mosambicensis* – Knobbly creeper
Eragrostis rigidior	*Peltophorum africanum* - Weeping wattle
Eragrostis rotifer	*Schotia brachypetala* - Weeping boer-bean
Eragrostis superba	
Eragrostis trichophora	
Heteropogon contortus	
Hyparrhenia hirta	
Melinis nerviglumis	
Melinis repens	
Panicum maximum	
Perotis patens	
Pogonarthria squarrosa	
Schmidtia pappophoroides	

Setaria pumila
Sporobolus nitens
Sporobolus panicoides
Tragus berteronianus
Tricholaena monachne
Urochloa mosambicensis

2.5 Fauna

Aerial game counts are done annually in the reserve to monitor the presence and abundance of fauna. Counts are carried out using a helicopter which flies in a grid pattern across the reserve. In the 2013 aerial census, 21 species were identified with a total of 2086 individuals (Table 2.2).

Table 2.2: Table showing the main fauna species counted in 2013.

Species	**Total**	**Species**	**Total**
Felis sylvestris caffra - African Wild Cat	1	*Tragelaphus strepsiceros* - Kudu	197
Papio ursinus - Baboon Troops	5	*Panthera leo* - Lion	13
Diceros bicornis - Black Rhino	5	*Chlorocebus pygerythrus* - Vervet Monkey Troops	2
Syncerus caffer - Buffalo	31	*Tragelaphus angasii* - Nyala	2
Tragelaphus sylvaticus - Bushbuck	10	*Raphicerus campestris* - Steenbok	14
Crocodylus niloticus - Crocodile	16	*Phacochoerus africanus* - Warthog	73
Sylvicapra grimmia - Duiker	12	*Kobus ellipsiprymnus* - Waterbuck	61
Loxodonta africana - Elephant	103	*Connochaetes taurinus* - Wildebeest	2

Cervus camelopardalis - Giraffe	56	*Equus quagga* - Zebra	64
Hippopotamus amphibius - Hippo	45	*Aepyceros melampus* - Impala	1323

Aerial game counts have been carried out annually since 2007, providing historical data for the 12 main herbivore species investigated in this study. Game count totals from 2007 to 2013 are depicted in Figure 2.2.

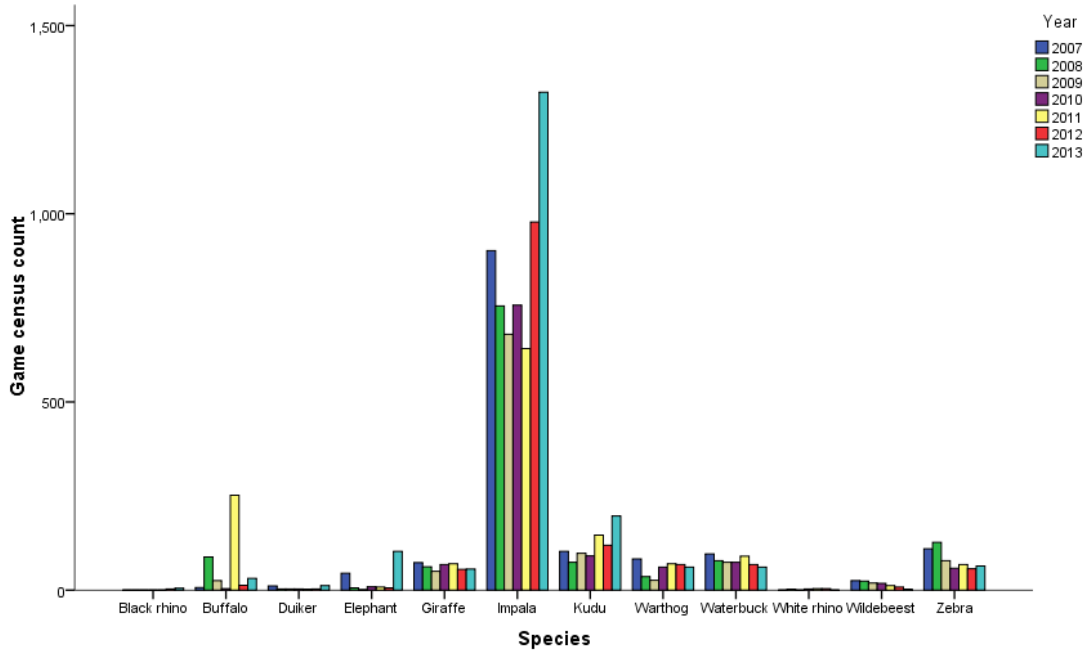

Figure 2.2: Graph showing population trends for the 12 herbivore species included in this study from 2007 to 2013.

It should be noted that aerial census data is biased towards larger species (Getz *et. al.* 2002) and therefore the accuracy of the aerial census data may be limited. For group living animals count data decreases in accuracy with decreases in sizes and numbers of group animals (Getz *et. al.* 2002), however consistency of methodology and time of year in which the census is carried out allows data to be compared across years to identify population trends.

2.6 Land use history

Historical land use of the study site was predominantly cattle farming, cultivation and game farming. Many artificial waterholes were built for these farming practices and many still remain within the reserve.

Fences around the OWNR area were dropped between the OWNR and the rest of Balule in 2005 making it a valuable study area in terms of changing species demographics as wildlife such as elephants (*Loxodonta africana*) re-colonise Balule.

2.7 Climate

Climate for the savannah biome is characterised by a clearly defined summer-rainfall pattern (Mucina & Rutherford 2006), where the majority of rainfall occurs between October and April, the summer period. The remaining months are winter, which is cooler and dryer, characterised by night-time temperatures that drop as low as 0°C in high altitude areas (Mucina & Rutherford 2006). According to Mucina & Rutherford (2006), day-time temperatures in South African savannahs rarely drop below a daily minimum of 20°C in July (winter), or 26°C in February (summer). These figures concur with data obtained from the study site during the study period (2013), shown in Table 2.2. Climate data was collected from a weather station located at the OWNR research facility.

Table 2.3: Temperature and rainfall data per month for 2013.

	Temperature (°C)			
Month	**Mean daily maximum temperature**	**Mean daily minimum temperature**	**Mean daily temperature**	**Total Rainfall (mm)**
January	30.9	20.4	25.1	212
February	32.4	19.8	25.4	10
March	31.1	18.7	24.1	11

April	28.4	14.5	20.5	90
May	27.6	11	18.3	2
June	27.3	9	17.1	3
July	25.5	10	17.3	1
August	27.2	11.6	18.8	12
September	30.6	15	22.4	2
October	29.2	15.9	22.2	33
November	31.8	18.8	24.7	51
December	28.9	19.1	23.4	132

Total rainfall recorded for the study site in 2013 was 559mm. Mean monthly rainfall from 2010 – 2013 is shown in Figure 2.3.

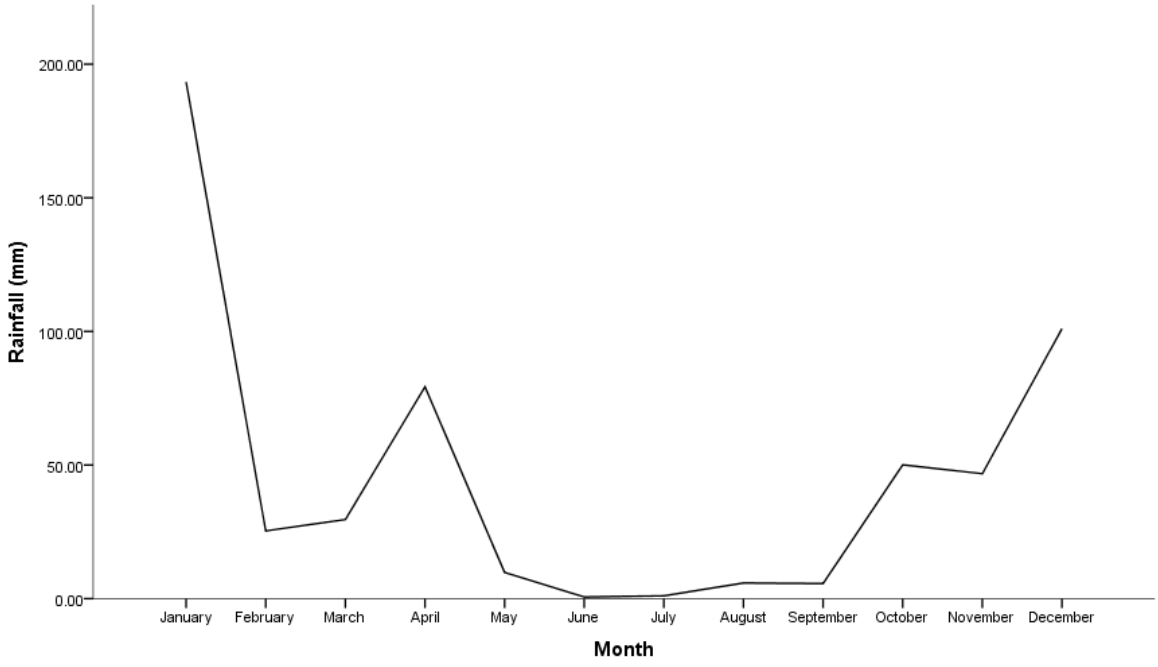

Figure 2.3: Mean rainfall per month for 2010 – 2013.

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Chapter 3 : Methodology

3.1 Waterhole selection

The positions of the waterholes in the Olifants West Nature Reserve are shown in Figure 3.1. A representative sample of these waterholes was selected to monitor their utilisation and assess the surrounding vegetation to establish relative impacts on habitat integrity by visiting herbivores.

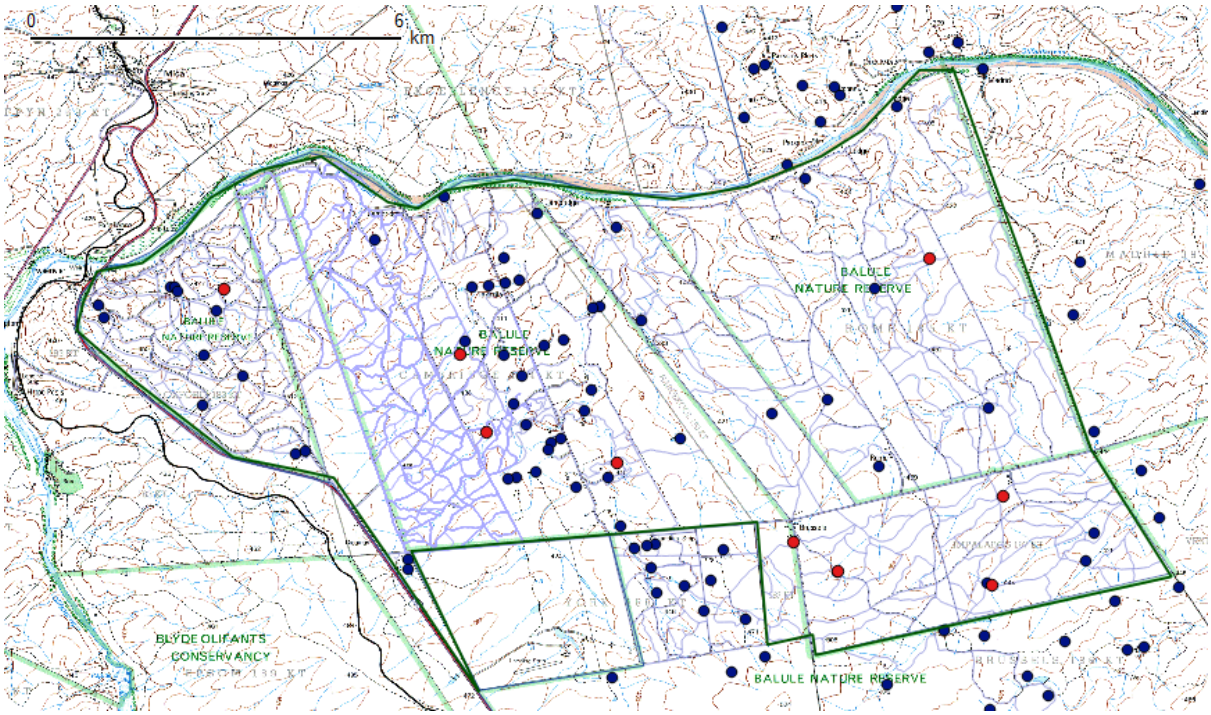

Figure 3.1: Map showing the locations of all waterholes at the study site. Study waterholes are indicated by red dots and other waterholes by blue dots.

Study waterholes were selected to represent the four main waterhole types in the reserve: earth dams, pans, reservoirs and troughs. In addition, waterholes selected covered a range of sizes and water sources (Table 3.1). All waterholes selected were permanent, providing water throughout the year. Where possible, selection was based on spatial orientation of the waterholes; however, there were constraints of availability of particular waterhole types

and practicality of access. Nine sites were selected as this was the greatest number that could be effectively monitored with the available camera traps as well as surveyed in a concise period of time. Of these sites, three waterholes were earth dams, three waterholes were pans and three waterholes were reservoirs. Reservoirs were typically associated with troughs, however, the trough associated with Nzulwini reservoir was non-functional for the duration of the study. The Nzulwini trough was therefore not monitored with camera traps but the troughs associated with both Nyala reservoir and Van Wyk's reservoir were. The reservoirs and troughs of Nyala and Van Wyk's were monitored separately with camera traps in order to produce an accurate account of wildlife visiting the waterholes. However, due to the close proximity of the reservoirs and troughs, only one set of transects were utilised for assessing the surrounding vegetation.

Table 3.1: Naming of artificial waterholes selected for this study, their type, water source and relative size.

Name of waterhole	**Type of waterhole**	**Source of water**	**Size**
Leopard's view	Pan	Solar pump	Small
Ngala	Earth dam	Solar pump	Medium
Nyala reservoir	Reservoir	Solar/wind pump	Medium
Nyala trough	Trough	Solar/wind pump	Small
Nzulwini	Reservoir	Manual pump	Medium
Oxford big dam	Earth dam	Wind pump	Large
Singwe big dam	Earth dam	Drainage	Large
Singwe bush camp	Pan	Wind pump	Small
Toni's dam	Pan	Manual pump	Small
Van Wyk's reservoir	Reservoir	Wind pump	Medium
Van Wyk's trough	Trough	Wind pump	Small

Earth dams are waterholes without a concrete base or sides (Figure 3.2a); reservoirs had a concrete base and high sides (Figure 3.2b); pans had a concrete base but low sides (3.2c); and troughs (like pans) had a concrete base and low sides; however, troughs were

specifically associated with reservoirs, whereas pans were not associated with other waterhole types (Figure 3.2d).

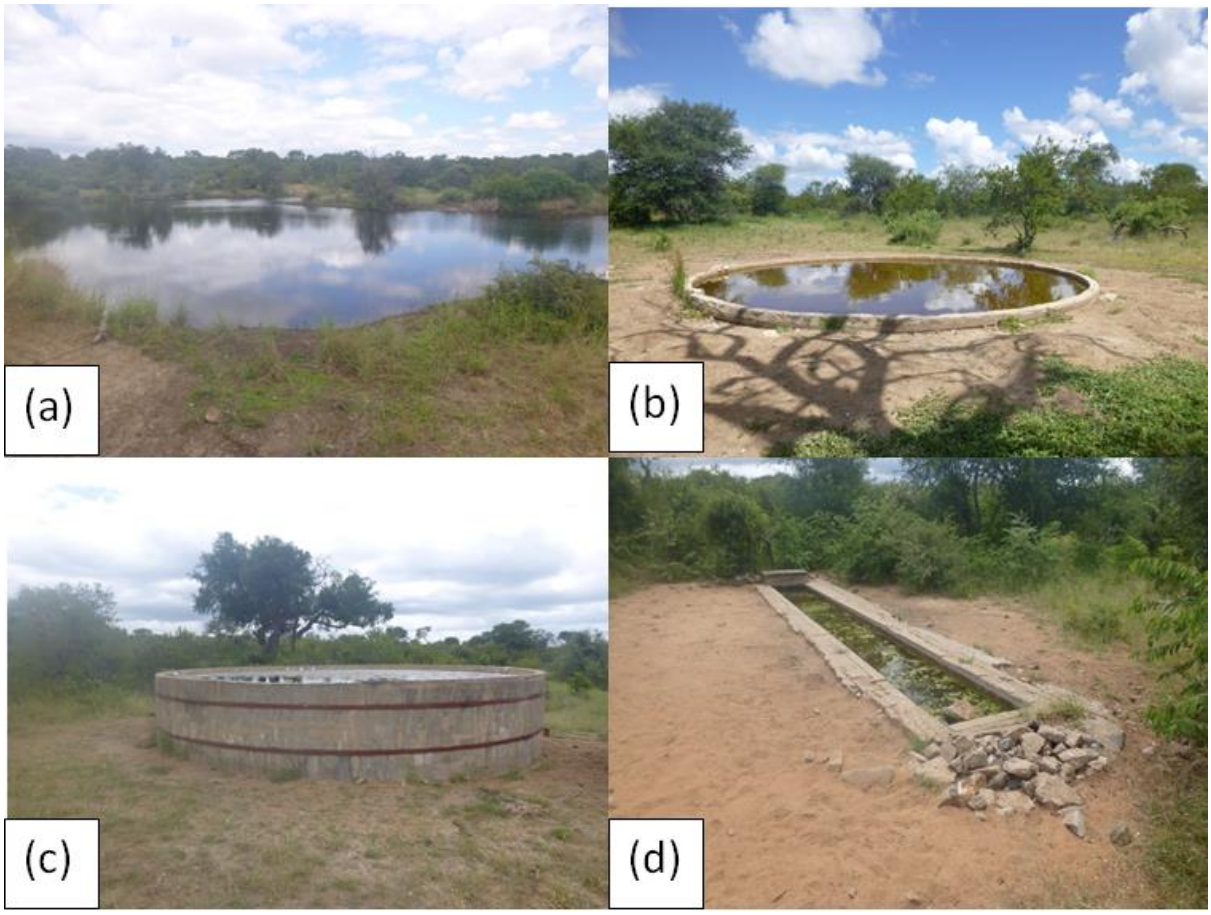

Figure 3.2: (a) Example of an earth dam, Singwe Big Dam. (b) Example of a pan, Toni's Dam. (c) Example of a reservoir, Nyala reservoir. (d) Example of a trough, Van Wyk's trough.

Waterhole sizes were determined according to the volumes of water they held, calculated using circumference and depth. Large waterholes held more than 1000m³ of water, medium waterholes between 100m³ and 1000m³, and small waterholes less than 100m³.

3.2 Herbivore utilisation of waterholes

3.2.1 Data collection

Herbivore utilisation of waterholes was established using camera traps, which were placed at each of the study waterholes.

A sightings-per-day value was calculated by dividing the total number of sightings at a particular waterhole by the number of days the waterhole was effectively photographed using camera traps. This allowed for direct comparisons between waterholes. To ensure maximum coverage of waterholes, the number of camera traps placed at waterholes varied according to the size of the waterhole. If rainfall affected the size of the waterhole, as it did at Oxford Big Dam and Singwe Big Dam, camera traps were either added or removed to ensure maximum coverage.

Data collected from camera trap photos included:

- Digital time stamps for each photograph. Arrival and departure times for animals visiting the waterholes were recorded as the times of the first and last photographs taken in a sequence of consecutive photographs for a particular visit. Visit duration was calculated as the difference between arrival and departure times. If there was a gap of five minutes or longer between photographs, and if it was not possible to confirm that the same individual or group was being photographed, subsequent photographs were treated as a separate visit.
- Whether a photograph was taken during the day or night was recorded as sunrise and sunset varied across the data collection period.
- All mammal species photographed at waterholes. All species were identified. If more than one species was identified in a set of photographs, each species was counted as a separate visit and the association between them was recorded. The 12 most frequently photographed herbivores were included in the analysis undertaken for this study. Hyaena (*Hyaena hyaena)*, lion (*Panthera leo)* and leopard (*Panthera pardus)* were also included in the analysis, since various studies indicate that

herbivore movements are influenced by the presence of these predators (Valeix *et. al.* 2009; Thaker *et. al.* 2011).

- Species included in the analysis are:
  1. Black rhino (*Diceros bicornis)*
  2. Buffalo (*Syncerus caffer)*
  3. Duiker (*Sylvicapra grimmia)*
  4. Elephant (*Loxodonta africana)*
  5. Giraffe (*Giraffa Camelopardalis)*
  6. Hyaena (*Hyaena hyaena)*
  7. Impala (*Aepyceros melampus)*
  8. Kudu (*Tragelaphus strepsiceros)*
  9. Leopard (*Panthera pardus)*
  10. Lion (*Panthera leo)*
  11. Warthog (*Phacochoerus africanus)*
  12. Waterbuck (*Kobus ellipsiprymnus)*
  13. White rhino (*Ceratotherium simum)*
  14. Wildebeest (*Connochaetes taurinus*)
  15. Zebra (*Equus quagga)*
- Numbers of individuals per visitation by the same species – this data was used to establish group or herd size.
- The sexes of individuals (where possible), to establish herd structure and demographics. An 'unknown' option was used when sex could not be determined.
- Age classes of individuals according to the following categories: infant, juvenile and adult.
- Activities of animals visiting the waterholes: drinking, cooling, wallowing, feeding/socialising and unknown. Drinking was recorded for animals that were drinking or when there was sufficient evidence to suggest that drinking had occurred i.e. rippled water next to an animal. Cooling was associated with submersion in water without wallowing in mud. Elephants were recorded to be cooling when spraying themselves with water. Wallowing was attributed to visitations where animals utilised patches of mud at the edges of some waterholes. Feeding/socialising

were categorised together as they are both activities occurring in the photographs, but not directly involving the waterhole. Unknown was attributed to a visitation in which the activity being carried out could not be reliably denoted.

3.2.2 Visitations

Frequency of visits to waterholes was considered in terms of numbers of observations and numbers of individuals visiting. For example, one visit may have consisted of many individuals. This was done to account for both frequency of occurrence of a species, as well as the total number of individuals of each species visiting a waterhole. Relative proportions of these measurements were calculated per waterhole type for comparison across waterhole types. Timings of visitations per species and waterhole types were also considered.

3.2.3 Species diversity

Species diversity was calculated using Simpson's index of diversity (Simpson 1949). Simpson's index states the probability of two individuals in a sample being from the same species. A greater index value indicates lower species diversity and a higher probability of two individuals in a sample being the same species.

3.2.4 Diet

Variation in utilisation between waterholes was investigated in terms of which species visited the waterholes and in terms of the foraging strategies (browser, grazer or mixed feeder) of these species. This was done because herbivore foraging strategies have a notable impact on the vegetation they utilise. Daily frequencies of visitors representing the different foraging strategies were recorded.

3.2.5 Group size and herd type

Average size of group per species was calculated and compared. There is variation in feeding patterns depending on herd type for buffalo and elephant (Shannon *et. al.* 2006; Hay *et. al.* 2008). Herd types identified included bachelor, breeding and lone male. Bachelor herds were defined as herds consisting of more than one male, lone males were single males, and breeding herds had females present. The relationship between group size and herd type with regard to duration of visit was also investigated.

3.2.7 Herbivore activity

Herbivore activity at waterholes was considered by proportion per species and per waterhole type. The data was represented graphically to show variations in the proportions each activity contributed to these variables.

3.2.8 Species electivity of waterholes

Species electivity was considered in terms of the water-dependency of each species relative to one another. Comparisons of electivity were made between different waterhole types. The Jacob's index of preference (Jacobs 1974) was used to determine relative water-dependency between species by indicating selection for or against waterhole types per species relative to species population sizes. This method was also used by Hayward & Hayward (2012) to determine water dependency of herbivores visiting waterholes.

3.3 The impact of artificial waterholes on habitat integrity

A scoring system for assessing habitat integrity was devised using multiple vegetation parameters including the herbaceous layer (grasses and forbs), height of woody species, the perceived direct impact from herbivores, and the diversity of woody species. In addition to this, a coverage estimation was made in the form of percentage of ground cover by woody species (basal), herbaceous cover and bare ground.

Data was collected from four transects placed in the four cardinal directions around each of the study waterholes (Figure 3.3). Due to the close association between the reservoirs and troughs of Nyala and Van Wyk's, these were considered as single study waterholes with four transects and not eight. Each transect consisted of five plots of ten square metres at 200m, 400m, 600m, 800m and 1000m from the centre of the waterhole. In total 220 plots were placed. This allowed for assessment of vegetation at different distances from waterholes. The locations of the plots were calculated using the distance measuring tool in Quantum GIS and using a GPS were located and marked in the field. The coordinates obtained in QGIS were used to mark the centre of each plot.

Vegetation surveys began on 3 December 2013 and ended on 16 January 2014. The locations of each plot are indicated in Figure 3.3. A control site with 10 control plots was identified outside the reserve for comparison. The control site had no water and was not influenced by herbivores. Control plots were visited during the same time frames as for the study waterholes.

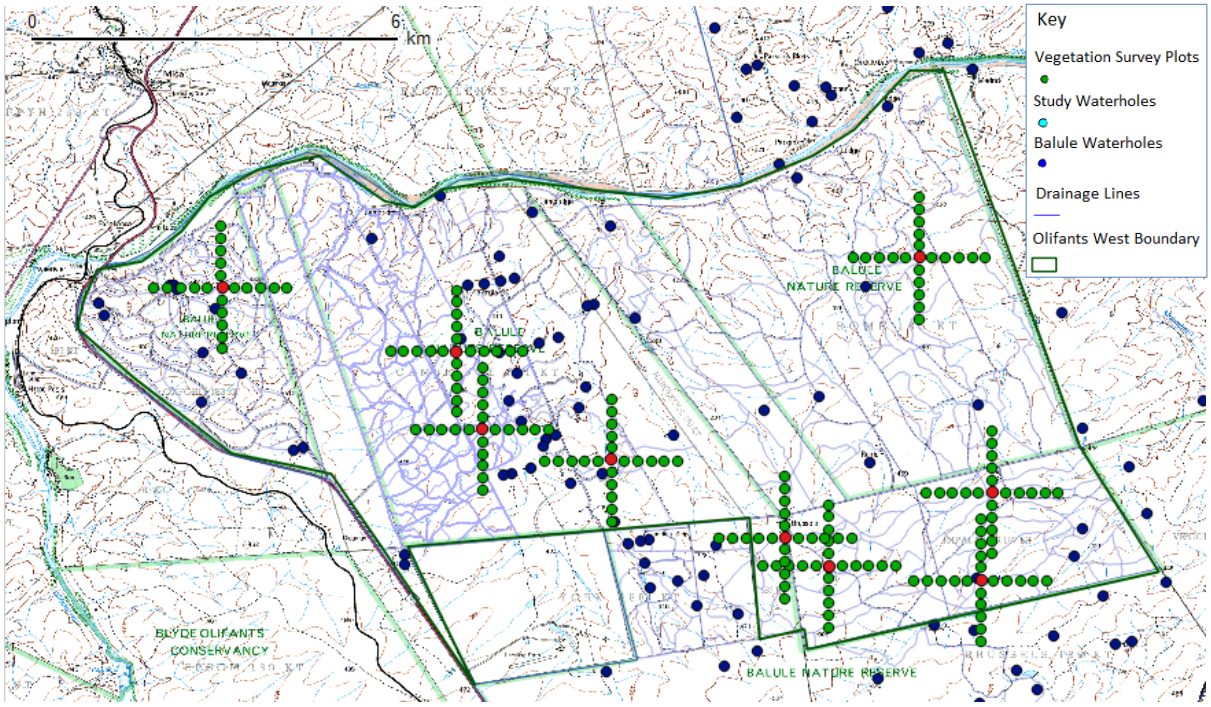

Figure 3.3: Map showing the location of all study waterholes and vegetation survey plots.

3.3.1 Herbaceous layer

The Ecological Index Method (Vorster 1982; Van Oudtshoorn 2012) was used to assess veld condition of the herbaceous layer. This was done using the step point method. One hundred step points were recorded across each plot. At each step, a stick was dropped onto the ground to record a 'hit' or 'miss'. Forbs or grass species touching the stick (a 'hit') were identified and recorded. A 'miss' was recorded when neither a forb or grass touched the stick.

The herbaceous vegetation was differentiated into several ecological status categories (Van Rooyen *et. al.* 1996; Van Oudtshoorn 2012): Increaser I, Increaser II, Increaser III, Decreaser, and forbs. These definitions elicited different scores according to their grazing value (Van Rooyen *et. al.* 1996). Table 3.2 shows the ecological status of each grass type and its corresponding score. The equation includes hits and misses.

Table 3.2: Definitions and veld condition score equations used for the different ecological status categories of herbaceous vegetation (Van Rooyen *et. al.* 1996).

Ecological status class	**Definition**	**Equation**
Decreaser	A grass species which is dominant in good veld which is well managed, but decreases when veld is mismanaged, overgrazed or under-utilised.	% D * 10
Increaser I	A grass species which increases when veld is selectively utilised or under-utilised.	% I1 * 7
Increaser II	A grass species which is dominant in poor veld and	% I2 * 4

	increases as a result of overgrazing.	
Increaser III	A grass species which is dominant in poor veld and increases as a result of heavy overgrazing.	% I3 * 1
Forbs	Weeds, invaders and forbs.	% F * 1

3.3.2 Woody layer

Each woody species was identified and placed into one of five height class categories (<0.5m, 0.5m – 1.5m, >1.5m – 3.0m, >3.0m – 4.5m and >4.5m). In addition to the height of woody species, the level of herbivore impact per tree (recorded as low, medium or high), and the diversity of all woody species in a plot were calculated.

Impact from herbivores was assessed according to perceived disturbance to woody species. Disturbance was categorised as bent branches, broken branches, damage to trunk, trunk pushed over, and dead. A negative score was attributed to each of these disturbance categories, depending on the degree of disturbance. The extent of each disturbance type was quantified and scored according to whether it was perceived as low, medium or high.

Woody species diversity per plot was calculated using Simpson's index of diversity. Every woody species in a plot was identified to the species level except in the cases of *Commifera*, *Grewia* and *Boscia* species. These were identified to the genus level due to similarities between members of the group (Van Wyk & Van Wyk 2013) and for greater efficiency in the field.

3.3.3 Habitat score

A unique habitat score was determined using an equation combining data from the herbaceous layer and woody layer to represent habitat integrity as a single numerical figure.

3.4 Assessing the influence of waterhole design on habitat integrity with reference to specific herbivores

Chapter six combines data collected in chapters four and five to investigate relationships between herbivore utilisation of waterholes and the habitat integrity of surrounding vegetation.

3.5 Statistical analysis

Correlation tests were carried out using the entire data set, and with data for individual waterholes to assess the influence waterhole design has on herbivore utilisation.

All statistical analyses were carried out using SPSS vs. 21. Prior to analysis, distribution tests were done to see if collected data had a normal distribution. A Shapiro-Wilk test for normality (Zar 2010) was used along with histograms to show distribution of data. Where normal distribution was not achieved, non-parametric statistical tests were done.

Statistical significance was included from the 95^{th} percentile, with *p*-values set at 0.05.

3.6 GIS study

Quantum Geographical Information System (QGIS) was used to determine minimum distance of study waterholes to other water sources, number of waterholes within a kilometre radius of study waterholes, and minimum distance from study waterholes to drainage lines.

The distance of each plot to the nearest waterhole was calculated using the distance matrix vector analysis tool provided by QGIS using Balule's Waterhole vector layer (Figure 3.3). The density of waterholes in a one kilometre radius of a plot was calculated using the nearest

neighbour test analysis in QGIS. Distance to drainage lines may affect vegetation scores due to a change in habitat type in a riparian zone (Jacobs & Naimon 2007), with this in mind, minimum distance to drainage lines was calculated using the minimum distance vector analysis tool in QGIS.

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Chapter 4 : Herbivore utilisation of waterholes

4.1 Introduction

Different species of herbivore have different water requirements (Owen-Smith 1996; Smit *et. al.* 2007; Hayward & Hayward 2012). How and when herbivores utilise water may be affected by a number of different factors including: risk of predation, competition, group size, group composition, time of day or night, seasonality, and water availability. Herbivore response to predation risk plays an important role in waterhole selection and utilisation (Fischoff *et. al.* 2007; Davidson *et. al.* 2010; Crosmary *et. al.* 2011). In addition to this, there may be a need to avoid inter-species competition (Valeix *et. al.* 2007; Hayward & Hayward 2012). The degree to which an individual is affected by these influences, is associated with group size and composition (Morrell *et. al.* 2011), time of day or night (Mukinya 1977; Hayward & Hayward 2012) or season, accompanied by a greater association with surface water during the dry season (Smit *et. al.* 2007).

Water dependency varies between species, with studies showing grazers such as zebra and wildebeest to be more water dependent than browsers such as kudu and giraffe (Smit *et. al.* 2007; Hayward & Hayward 2012). This is not necessarily an invariable rule; as one study shows steenbok, a browser, to have a higher water-dependency than waterbuck, a grazer (Hayward & Hayward 2012). Further to this, different species may utilise waterholes in different ways. For example, buffalo, elephants, rhino and warthog are reported to not only drink at waterholes, but also to submerge themselves in the water to benefit from evaporative cooling, or to wallow in mud (Waldram *et. al.* 2008; Vanschoenwinkel 2011; Dunkin *et. al.* 2013). With this in mind, the importance of waterholes and their design surpasses their relevance in terms of only providing drinking water. Water dependency varies seasonally, with dependency increasing during the dry season (Smit *et. al.* 2007;

Hayward & Hayward 2012). Mud wallowing is also more frequent during the rainy season (Owen-Smith 1992).

According to Hayward & Hayward (2012) timings of waterhole utilisation by herbivores is dependent on a number of factors including predator avoidance and avoidance of inter-species competition. Waterholes are considered high-risk areas in terms of predation and as such peak activity of prey species at waterholes has been found to coincide with reduced predator activity (Hayward & Hayward 2012). Activity at waterholes varies between night and day as most predators are nocturnal (Hayward & Hayward 2012), resulting in prey species avoiding predators by utilising waterholes during the day. The least variation in night versus day activity at waterholes is seen in the mega-herbivores (elephant and rhino), which are not typically prey species (Mukinya 1977; Valeix *et. al.* 2007).

Interspecies competition affects the temporal variation in waterhole utilisation by herbivores. Elephants are reported to displace other species at waterholes (Berger & Cunningham 1998; Valeix *et. al.* 2007). According to Berger & Cunningham (1998), displacement as a result of interspecies competition is usually based on size, suggesting that when elephants co-exist with rhinos, rhinos are displaced, but when rhinos are the largest herbivore in the area, they displace smaller herbivores. Hayward & Hayward (2012) reports that inter-species associations become more frequent with smaller herbivores. In addition to this, Hayward & Hayward (2012) do not record buffalo associations with other species at waterholes, suggesting that buffalo either avoid other species when visiting waterholes, or their presence deters other species. Waterhole availability and type is relevant to herbivores in terms of competition. More waterholes may reduce competition, as may certain waterhole types if they are preferable to different species.

Competition at waterholes has also been linked to gender, with elephant cows being less tolerant of other waterhole users than bulls, and male rhino being more likely to displace other species than female rhino (Berger & Cunningham 1998). Based on these findings, it is relevant to consider herbivore group dynamics. Group size is also important as studies suggest female elephants dominate over other species at waterholes, possibly related to larger group sizes of female elephant herds (Berger & Cunningham 1998). The role that

herding plays in terms of predation risk is another factor affecting group size (Morrell *et. al.* 2011).

This chapter investigates the variation between waterhole utilisation across waterhole types and species, taking into consideration time of day, length of stay at a waterhole, group demographics and animal activity. Data recorded using camera traps placed at different types of waterholes were used to investigate which animals utilised the different types of waterholes, when they utilised the waterholes, and how they utilised the waterholes. This monitoring allowed the profiling of waterhole utilisation by herbivores, improving our understanding of the effects that different waterhole types have on vegetation, and whether such effects are related to waterhole type/design or not.

4.2 Methodology

4.2.1 Camera traps

Camera traps were used to monitor waterholes. Camera traps were put out from 23 February 2013 to 9 September 2013. Camera traps monitored waterholes 24 hours a day, seven days a week and were triggered by diurnal and nocturnal animal movements.

Cameras used were Bushnell (model 119466), Tasco (model 9215), Scoutguard (model SG550) and Reconyx Rapidfire (RC55). Camera settings were standardised for all camera types to take 5 megapixel photographs every 1.2 seconds once movement was detected. All cameras were capable of taking infrared photos at night. The distance range of the various cameras varied from 30ft (Tasco), 45ft (Bushnell), 50ft (Scoutguard) to 80ft (Reconyx).

Camera traps were positioned to maximise the percentage of waterhole edge covered, with more camera traps being used to cover larger waterholes (Table 4.1). Camera traps were checked every seven days to ensure that they were still functioning and had not been displaced. Data collected from the camera traps provided information about the number of days each waterhole was effectively photographed by the camera traps. Since some

waterholes were more consistently monitored by camera traps than others, a sightings per day value was calculated by dividing the number of sightings at a waterhole by the number of days the waterhole was effectively monitored. This allowed for direct comparison of visiting species between waterholes. The number of camera traps deployed at Singwe Big Dam and Oxford dam varied depending waterhole size which was affected by rainfall.

Table 4.1: Number of days each waterhole was monitored and the number of camera traps used to monitor the waterholes.

Waterhole	**Number of camera traps**
Leopard's View	1
Ngala dam	1
Nyala reservoir	1
Nyala trough	1
Nzulwini reservoir	1
Oxford dam	2/3
Singwe Big Dam	2/3/4
Singwe Bush Camp	1
Toni's pan	1
Van Wyk's reservoir	1
Van Wyk's trough	1

Photographs produced by the camera traps were dated and time-stamped to allow accurate recording of the time photographs were taken. This provided data on the time of day that herbivores utilised waterholes, and the duration of stay at waterholes by herbivores. Seasonal variation was not considered as the camera trap study was done in winter.

As mentioned previously, species investigated in this study were:

1. Black rhino, *Diceros bicornis*
2. Buffalo, *Syncerus caffer*
3. Duiker, *Sylvicapra grimmia*

4. Elephant, *Loxodonta africana*
5. Giraffe, *Giraffa camelopardalis*
6. Hyaena, *Hyaena hyaena*
7. Impala, *Aepyceros melampus*
8. Kudu, *Tragelaphus strepsiceros*
9. Leopard, *Panthera pardus*
10. Lion, *Panthera leo*
11. Warthog, *Phacochoerus africanus*
12. Waterbuck, *Kobus ellipsiprymnus*
13. White rhino, *Ceratotherium simum*
14. Wildebeest, *Connochaetes taurinus*
15. Zebra, *Equus quagga*

The reason that these species were included was that they had large enough sample sizes to ensure the reliability of analyses. As these species were most frequently recorded at the waterholes it was deduced that these species would have the greatest impact on vegetation. Not all species known to be present in the study site were included because the study site is part of an open system and therefore it would be impossible to control for all species. Hyaena, leopard and lion were also included in the study as they influence herbivore movement patterns (Valeix *et. al.* 2009; Thaker *et. al.* 2011).

4.2.2 Visitations

A single visitation to a waterhole was defined as a single photograph or sequence of photographs isolated by a minimum of five minutes from any other photographs according to the time-stamp. Number of visitations per species to a waterhole per day was calculated by dividing the total number of visitations to a particular waterhole by a species, and dividing this by with the number of days camera traps effectively monitored the waterhole. This calculation was also applied to the number of individuals of a species visiting the waterholes.

The timings of visitations (time of day) and duration of stay per herbivore species were used to determine waterhole utilisation patterns. Duration of stay at a waterhole was calculated by subtracting a species departure time from its arrival time at the waterhole.

4.2.3 Animal species diversity

Species diversity was calculated using total number of different animal species utilising a waterhole (Simpson's index of diversity - Equation 4.1b; derived from Simpson's Index - Equation 4.1a). Simpson's index gives the probability of two individuals in a sample being from the same species and uses a range of values between 0 and 1. A greater value indicates a higher probability reflecting lower species diversity. Simpson's Index of Diversity allows for a clear comparison between waterholes in terms of the diversity of animal species visiting them.

Equation 4.1: (a) Simpson's Diversity (Simpson 1949) (b) Simpson's Index of Diversity.

$$\text{(a) } D = \frac{\sum n(n-1)}{N(N-1)} \qquad \text{(b) } 1 - D = 1 - \frac{\sum n(n-1)}{N(N-1)}$$

n = total number of individuals from a particular species

N = total number of individuals in the sample

4.2.4 Diet

Animal species were categorised according to foraging strategy, since quantities and types of foragers influence the vegetation surrounding waterholes, for example giraffe (a browser) target woody species (Bergström 1992). Foraging strategies included in the analysis were browser, grazer and mixed feeder. Browsers were defined as species foraging predominantly on woody plants, grazers predominantly on grasses, and mixed feeders on both woody plants and grasses. Table 4.2 differentiates between study animals in terms of foraging strategies. In this study, the frequency of occurrence of each foraging strategy was

analysed in terms of the number of individuals from each foraging category visiting the waterholes daily. Variation between waterhole types was also investigated.

Table 4.2: Species included in the study and their foraging strategies.

Foraging strategy	Species
Browser	Black rhino Duiker Giraffe Kudu
Grazer	Buffalo Waterbuck Warthog White rhino Wildebeest Zebra
Mixed feeder	Elephant Impala

4.2.5 Group size and herd type

The number of individuals in a group visiting a waterhole was counted using camera trap photographs. Where there was more than one camera trap present, the group size was taken from the camera trap showing the highest number of individuals to avoid counting individuals twice. Where markings, ear patterns (elephant), tusk size (elephant), and ear notches (rhino) could reliably identify individuals, these were used. Average group size per species was calculated and compared. Variation in group sizes visiting different waterhole types was investigated since waterhole types varied in terms of perceived risk from predators (Valeix *et. al.* 2009; Morrell *et. al.* 2011). In addition to the number of individuals per group, the age and sex of the individuals was also recorded to determine herd type i.e.

visits by buffalo and elephant were categorised by herd type to investigate variation in waterhole type utilisation. Only Elephant and Buffalo were analysed in this way as their feeding patterns vary depending on herd type (Shannon *et. al.* 2006; Hay *et. al.* 2008). Herd types were categorised as bachelor, breeding or lone male. Bachelor herds were defined as herds consisting of more than one male and no females present, breeding herds were defined as herds in which both males and females were present, and single male visits were identified as lone males.

Duration of stay was correlated with group size to determine if larger group sizes spent more time per visitation at waterholes.

4.2.6 Herbivore activity

Activity during a visitation to a waterhole was recorded as either a single activity or a combination of activities if more than one activity could be identified. Activities were categorised as drinking, cooling, wallowing and feeding/socialising. Feeding/socialising were categorised together as they represented activities that were not directly related to utilisation of waterholes. Activities that could not be identified from photographs were categorised as 'unknown.' If the activity was not directly observed in the photographs, but could be inferred, it was categorised according to the inference. An example of this would be an elephant that was photographed with a wet trunk; the photograph does not depict the activity of drinking but the wet trunk strongly suggests that the elephant has been drinking.

Combinations of activities occurring at waterholes were presented graphically to accurately show the way waterholes were being utilised. It was uncommon for cooling, wallowing and feeding/socialising to occur in isolation.

Herbivore activity at waterholes was considered for different species visiting the different waterhole types. The relative durations of each activity and their timings throughout the day were recorded.

4.2.7 Species electivity of waterholes

Species electivity was investigated to assess waterhole design to determine whether herbivores select certain waterhole types over others. The Jacobs index (Equation 4.2) was used to show variation in selection for or against certain waterhole types by the different species visiting them. The Jacobs index has been used by Hayward & Hayward (2012) to determine water dependency in a variety of species, and was used in this study to show relative water-dependency between species at different waterhole types. Index values range from negative one to positive one, with negative scores indicating selection against a particular waterhole type, and positive scores indicating selection for a particular waterhole type.

Equation 4.2: Jacob's index equation (Jacobs 1974).

$$D = \frac{r - p}{r + p - 2(rp)}$$

r = the proportion of all individuals from a species visiting a waterhole per day

p = the proportion a species represents out of all species included in the study

Jacobs index was calculated for each waterhole type to show variation in selection of waterhole types. This allowed comparisons of frequency of occurrence of individuals per day for species visiting the various waterhole types, while accounting for relative population size within the study area.

4.2.8 Statistics

The statistical tests carried out in this chapter are listed in Table 4.3.

Table 4.3: All statistical tests carried out in Chapter 4.

Statistical test	**Variable I**	**Variable II**
Kruskal-wallis	Time of visitation	Megafauna, predator, prey
	Duration of visit	Foraging strategy
	Group size	Species
	Group size	Waterhole type
	Group size	Waterhole size
	Jacob's index	Waterhole type
Pearson's correlation	Number of predator visitations	Number of visitations of prey
	Duration of visit	Group size

4.3 Results

4.3.1 Camera traps

Table 4.4 shows the number of days each waterhole was effectively covered by camera traps between the 3 March 2013 and 13 September 2013. The least number of days of effective coverage of a waterhole by camera traps was at Oxford dam, followed by Nyala reservoir and Van Wyk's reservoir. Number of days varied due to technical errors occurring with cameras resulting in reduced number of days of effective coverage.

Table 4.4: Deployment and removal dates of camera traps at the study waterholes with number of days of effective coverage for these periods.

Waterhole	**Camera trap deployment date**	**Camera trap removal date**	**Number of days of effective coverage**
Leopard's View	03.03.13	07.09.13	144
Ngala dam	03.03.13	07.09.13	130

Nyala reservoir	09.03.13	13.09.13	84
Nyala trough	03.03.13	08.06.13	104
Nzulwini reservoir	03.03.13	07.09.13	133
Oxford dam	17.03.13	27.07.13	81
Singwe Big Dam	09.03.13	07.09.13	154
Singwe Bush Camp	03.03.13	07.09.13	153
Toni's dam	03.03.13	31.08.13	155
Van Wyk's reservoir	03.03.13	13.09.13	92
Van Wyk's trough	03.03.13	07.09.13	140

A total of 25 different animal species were recorded by the deployed camera traps over the study period. The most frequently recorded species was elephant, with a total of 770 separate visitations recorded. Elephants visited the study waterholes 299 more times than the next most frequently recorded species, impala. The 15 most frequently recorded animal species (Table 4.5) were included in this study. Of these 15 species, 12 were herbivores, and three predators.

Table 4.5: Species recorded at all waterholes with the number of visitations recorded per species.

Species	**Number of visitations**	**Species**	**Number of visitations**	**Species**	**Number of visitations**
Elephant	770	Lion	62	Aardvark	9
Impala	471	Hyaena	59	Steenbok	7
Warthog	390	Duiker	40	Hippo	5
Giraffe	340	Wildebeest	30	Wild dog	4
Zebra	296	Leopard	28	Caracal	4
Waterbuck	227	White Rhino	27	Bushbuck	1
Black rhino	157	Jackal	19	Nyala	1
Kudu	119	Porcupine	14		

Buffalo	90	Civet	10		

4.3.2 Visitations

The number of visitations to a waterhole is represented as the number of visits per day by the 12 herbivore species. The most visited waterhole on a daily basis was Leopard's view, a pan, with an average of 3.69 visits per day. The least visited waterhole per day was Nyala trough with 0.69 visits per day. When considering the influence of waterhole type on frequency of visitations, Earth dams had the highest average number of visitations per waterhole with 3.10 visits per day. Pans also had a high frequency of visits with 2.81 visits per day. Reservoirs had the least number of visits on average per day with 1.31 and troughs had 1.42 visits.

The number of visitations per waterhole type does not necessarily provide an accurate indication of impact to surrounding vegetation, since only the number of visits for the 12 herbivore species studied are taken into consideration. The total number of individual animals to visit the waterholes is not accounted for. With this in mind, further analysis considered the number of individuals per species to visit a waterhole. When considering the number of individuals of each species visiting waterholes, elephant made up the greatest proportion of individuals to visit reservoirs and troughs, while impala made up the greatest proportion of individuals to visit earth dams and pans (Figure 4.1).

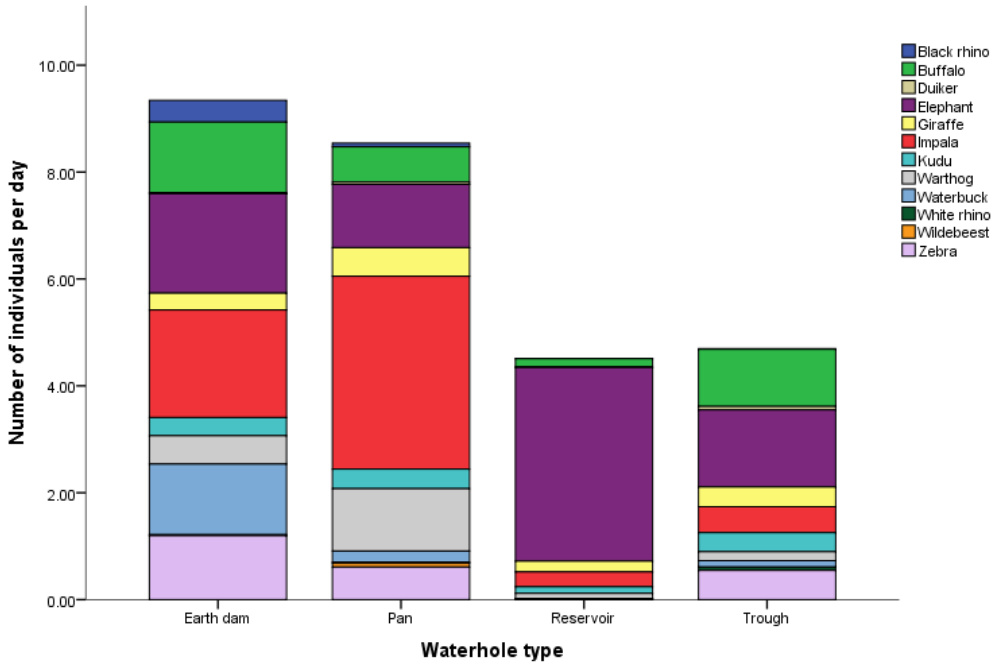

Figure 4.1: Proportional representation of herbivore species visiting the different waterhole types in terms of number of individuals for each of the 12 herbivore species studied.

Predator presence had to be considered due to the influence that predators have on herbivore movement patterns and their utilisation of waterholes (Thaker *et. al.* 2009; Valeix *et. al.* 2011). The most frequent occurrence of predators at the waterholes was recorded at pans, with a combined mean of 0.14 visits per day for hyaena, leopard and lion. At earth dams, a mean of 0.10 visits per day was recorded, and at reservoirs 0.07 visits per day. Troughs had the lowest number of predator visitations of 0.06 visits per day. Prey visitations peaked around the middle of the day and were lowest at dusk and dawn when predators were most active (Figure 4.2). Elephant, black rhino and white rhino, categorised as megafauna, also showed a peak in activity around midday; however, this was less pronounced than for other herbivore species which were categorised as prey. Despite this, statistically there was no significant variation in the times of utilisation between megafauna, predators and prey (x^2=1.58, df=2, p=0.45). In addition, the number of visitations per day by predators did not affect number of visitations per day by prey species (r=0.03, df=8, p=0.37).

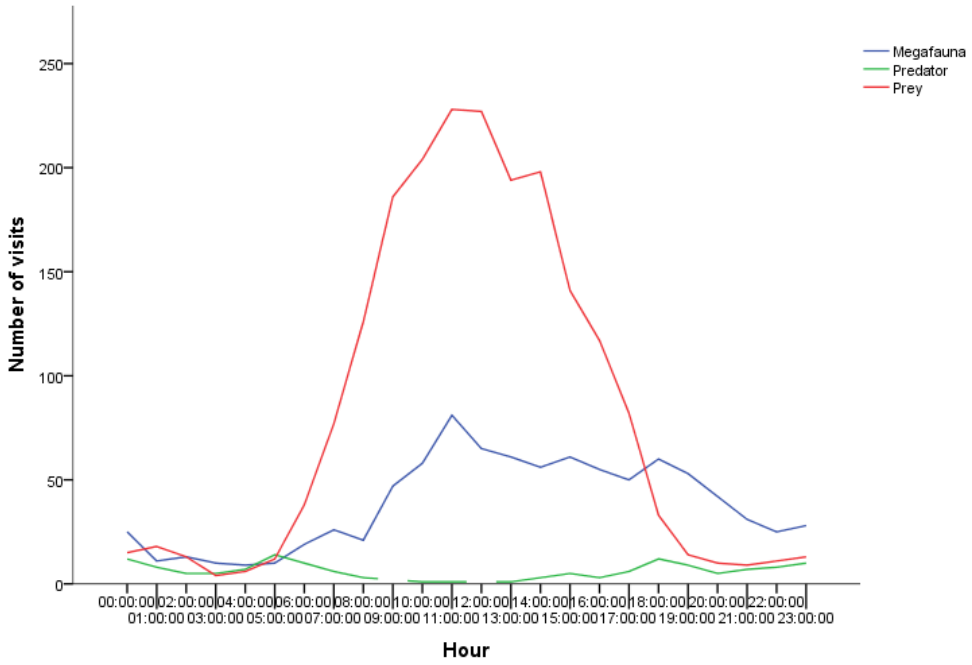

Figure 4.2: Numbers of observations per hour of the day for megafauna, predators and the 12 herbivore species.

Duration of visits to waterholes may be significant when considering herbivore impact on habitat integrity, as a longer visit duration provides increased opportunities for overgrazing and trampling. The average visitation length for all waterhole types by the 12 most frequently occurring herbivore species was 7.4 minutes.

Visits were found to be longest for reservoirs, 12.3 minutes, followed by pans, 6.9 minutes and earth dams, 6.6 minutes, with troughs having the lowest mean visit duration, 6.0 minutes (Figure 4.3).

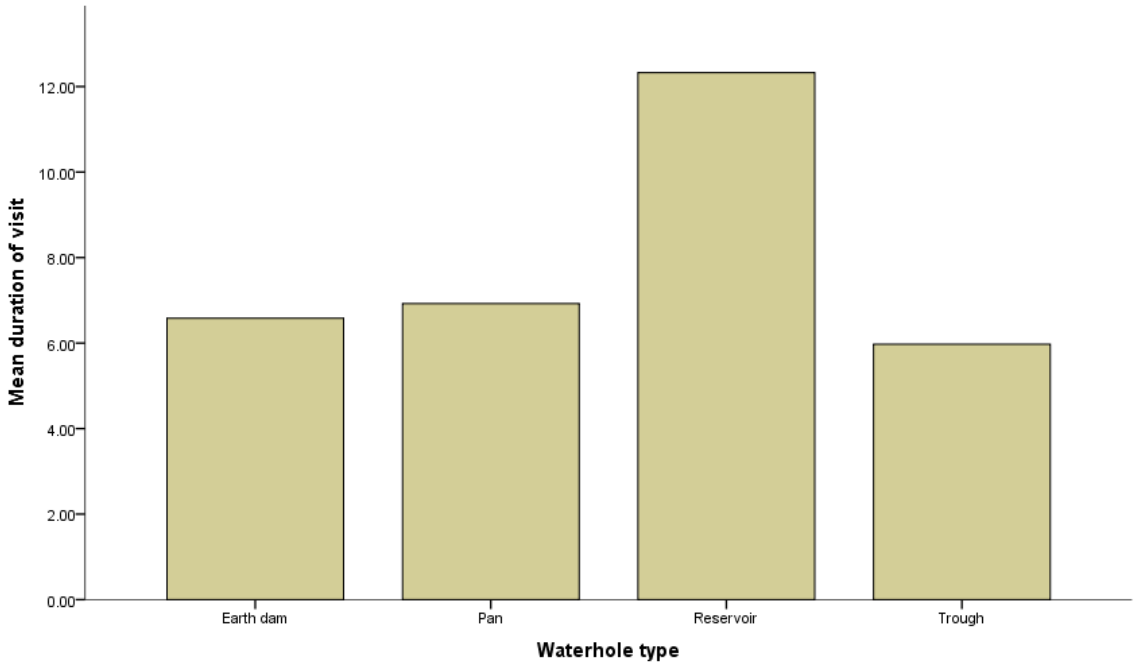

Figure 4.3: Mean duration of visits to each type of waterhole.

Figure 4.4 shows variation in mean duration of visit per herbivore species, with buffalo having the longest mean visit duration and duiker the lowest.

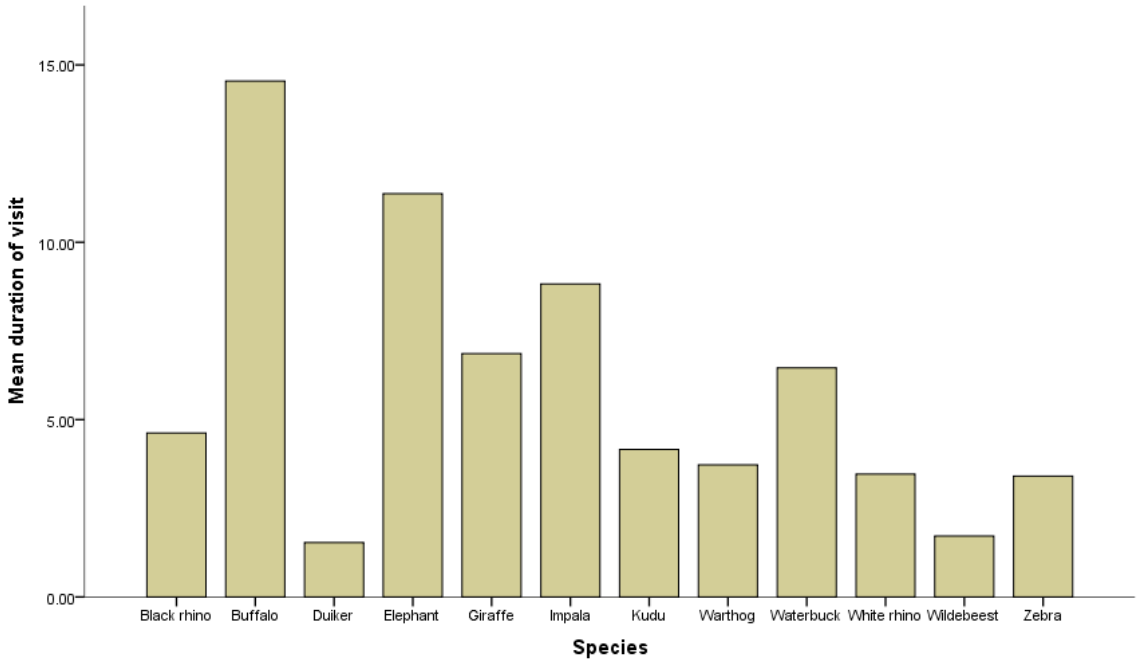

Figure 4.4: Mean visit duration in minutes for visitations by the 12 herbivore species.

4.3.3 Species diversity

According to Simpsons Index of Diversity, species diversity was found to be highest for pans, 0.953, and earth dams, 0.952 (Figure 4.5). Troughs had a Simpson's Index of Diversity value of 0.916 and the lowest species diversity of 0.815 was observed at reservoirs.

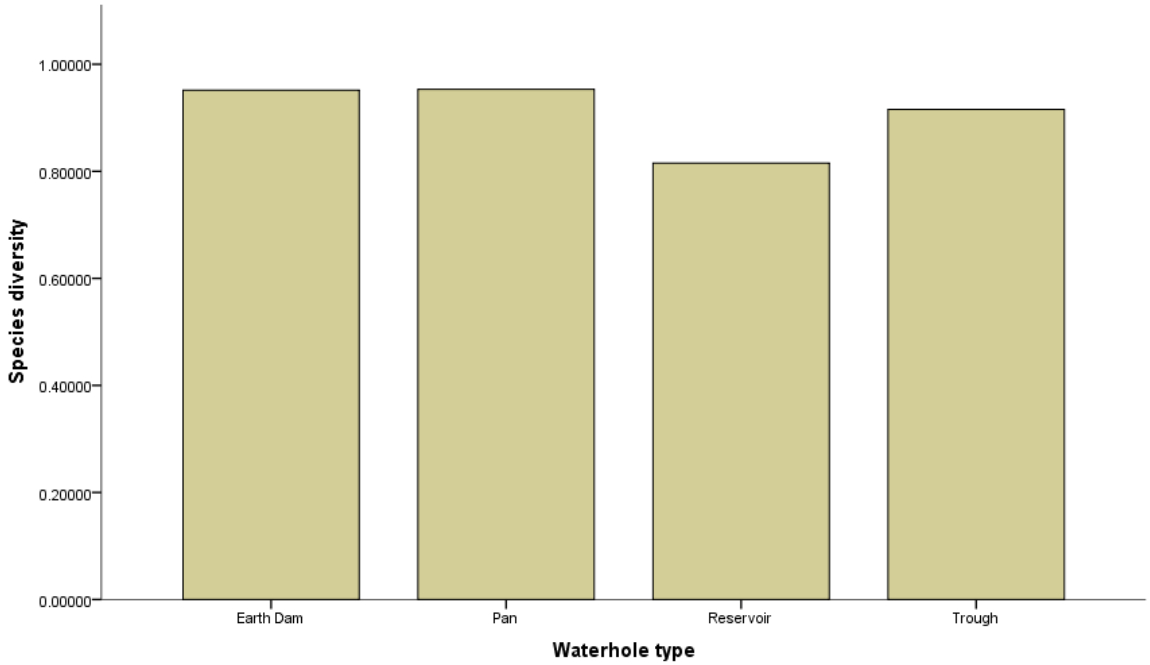

Figure 4.5: Species diversity for the different waterhole types according to the Simpson's Index of Diversity (higher values indicate greater diversity).

4.3.4 Diet

It is important to consider herbivore diets when investigating the impact that herbivores have on vegetation. Grazers have a greater impact on grass species, browsers on woody species, and mixed feeders impact both grasses and woody species. Herbivores utilising the study waterholes were divided into browsers, grazers and mixed feeders. Mean numbers of individuals per day for each foraging strategy visiting the different waterhole types are depicted in Figure 4.6. Mixed feeders were the most highly represented foraging category at pans, reservoirs and troughs. Grazers were the most highly represented foraging category at

earth dams, but least represented at reservoirs. Browsers were the least represented foraging category at earth dams, pans and troughs, but had increased representation at reservoirs compared to grazers.

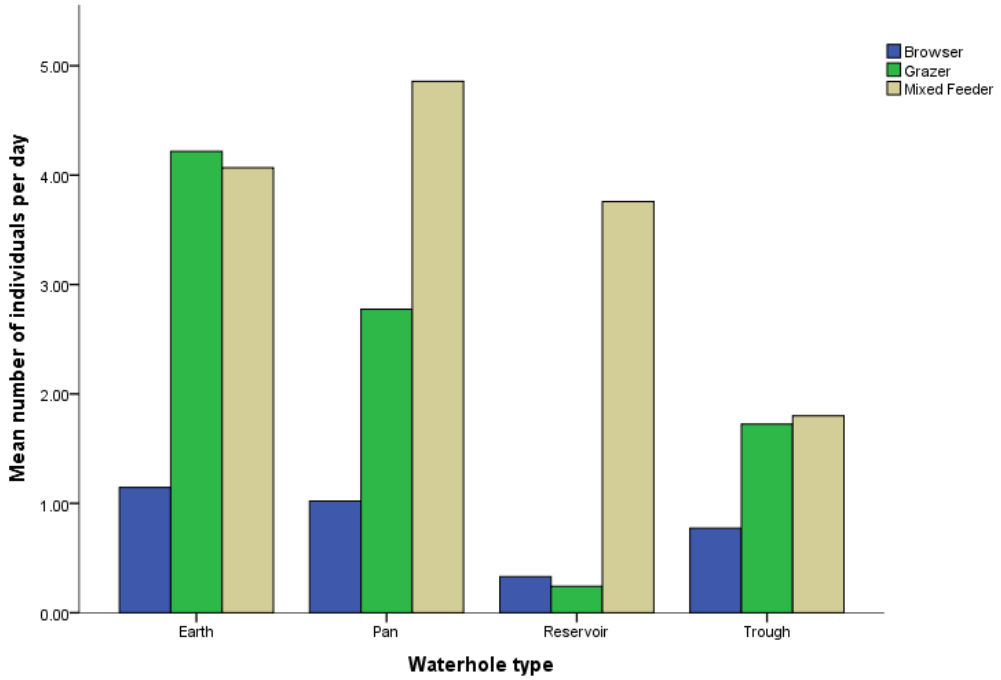

Figure 4.6: Mean number of individuals visiting the different waterhole types daily by foraging strategy.

The longest mean duration of stay at a waterhole by a foraging category was associated with mixed feeders, spending 10.4 minutes at a waterhole. Browsers had a mean duration of stay of 5.5 minutes and grazers 5.1 minutes. There was a significant association between foraging category and duration of visit to a waterhole (x^2=160.63, df=2, *p*=<0.01) showing that duration of visit is significantly related to whether a visit consists of browsers, grazers or mixed feeders.

4.3.5 Group size and herd type

The largest group sizes were associated with buffalo, impala and elephant. The largest buffalo herd recorded comprised 109 individuals, the largest impala herd recorded 38 individuals, and the largest elephant herd 21 individuals. When considering mean group size

per visit, buffalo had the largest mean group size, followed by impala (Figure 4.7). Elephant and kudu had the same mean group size of four individuals. The lowest mean group sizes were associated with duiker and white rhino that had a mean group size of one, and black rhino that had a mean group size of two. Statistically, group sizes differed between species (x^2=502.94, df=11, *p*=<0.01) but not between waterhole types (x^2=4.51, df=3, *p*=0.21) or waterhole sizes (x^2=5.79, df=2, *p*=0.06).

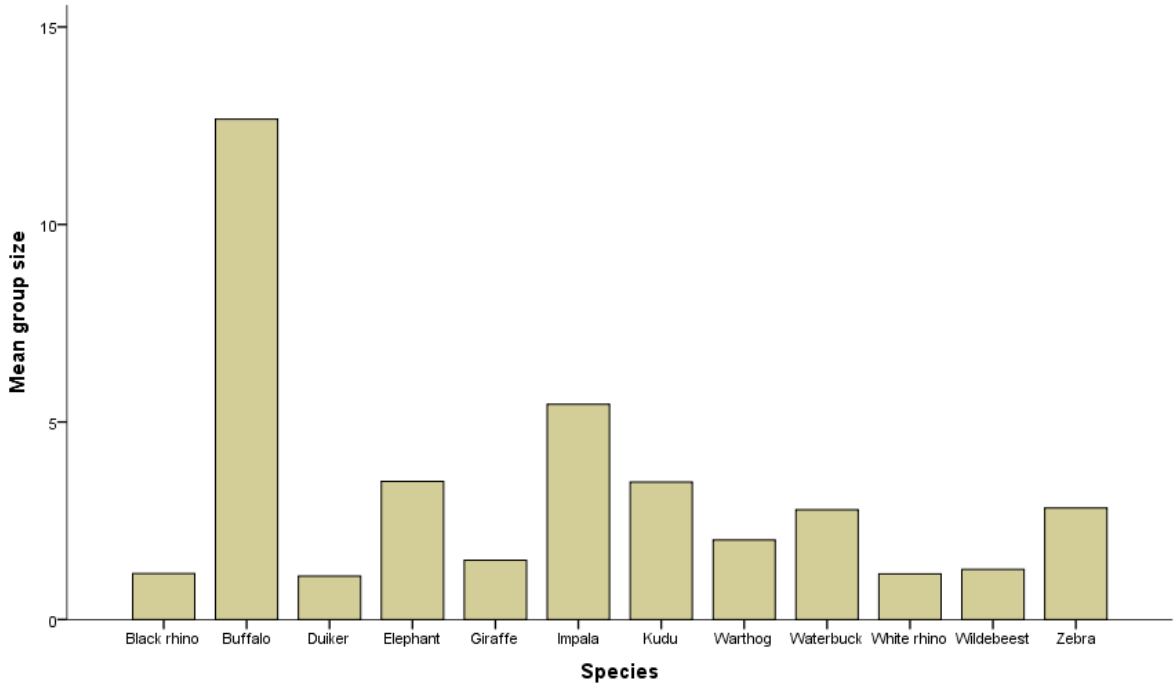

Figure 4.7: Mean group size per species visiting the study waterholes.

Larger group sizes were associated with longer durations of stay per species, with a positive significant correlation found between group size and duration of visit (r=0.33, df=3164, *p*=<0.01).

Since buffalo and elephant herd types vary in terms of behaviour (Hay *et. al.* 2006), their daily visits to waterholes were compared (Figure 4.8).

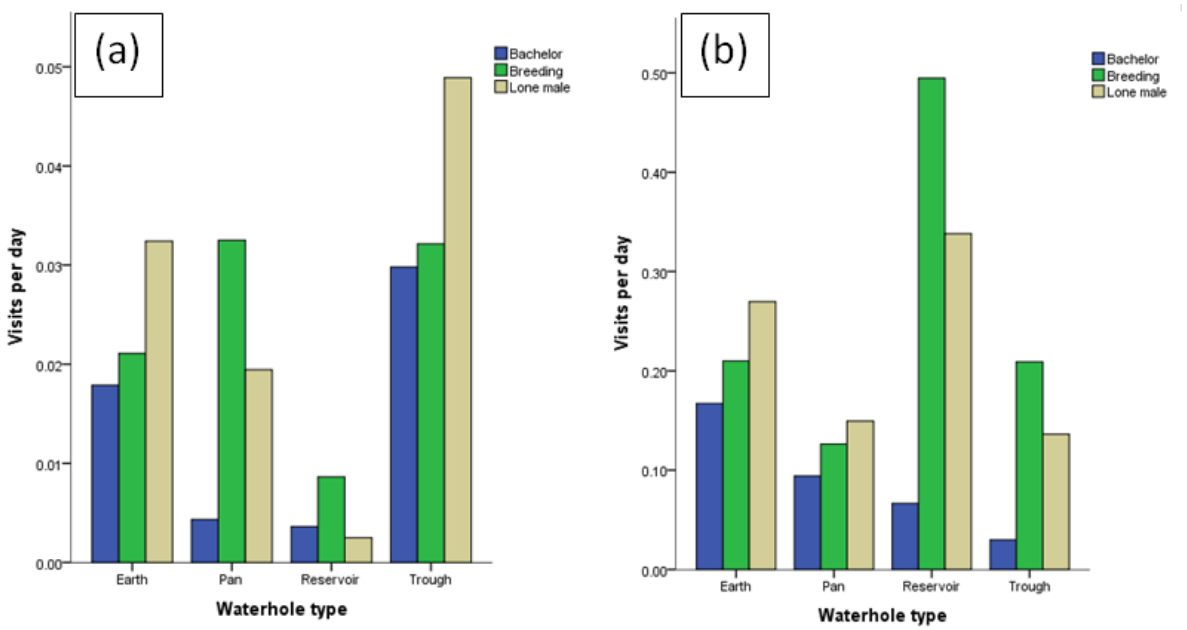

Figure 4.8: Number of visits per day to the different waterhole types by breeding herds, bachelor herds and lone males for (a) buffalo and (b) elephant.

The buffalo herd type with the highest number of visits per day to earth dams was lone males (Figure 4.8a). Buffalo lone males also had the highest number of visits per day to troughs; whereas, breeding herds occurred most frequently at pans and at reservoirs. Bachelor herds were the least common at earth dams, pans and troughs and lone males were the least common at reservoirs. The greatest number of visits per day by bachelor herds occurred at troughs, as did the greatest number of visits per day by lone males. Breeding herds occurred most frequently at pans, with little difference for pans and troughs.

As with buffalo, the most common elephant herd type to visit earth dams was lone males, followed by breeding herds and bachelor herds (Figure 4.8b). Pans had fewer visits per day by both lone males and breeding herds. Reservoirs had fewer visits per day by bachelor herds than did earth dams. Pans had more visits by breeding herds and lone males. Breeding herds and lone males were most common at reservoirs. The lowest representation of bachelor herds was at troughs, with breeding herds being the most common herd type at troughs, followed by lone males.

The herd type with the longest mean duration of visit was breeding herds for both buffalo and elephant. Buffalo breeding herds had a longer mean duration of visit than elephants

(Figure 4.9). For both buffalo and elephant, bachelor herds had the second highest mean duration of visit and lone males had the lowest mean duration of visit. Lone male buffalo spent less time at waterholes than lone male elephants.

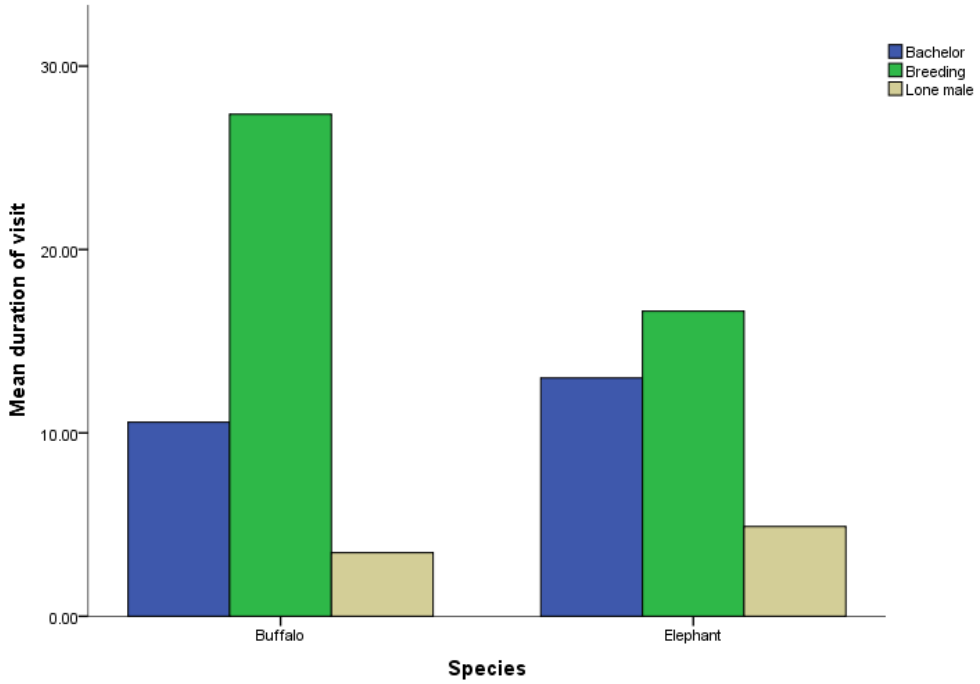

Figure 4.9: Mean duration of visit for different herd types of buffalo and elephant.

The largest herd sizes for both species were associated with breeding herds, followed by bachelor herds and lone males.

4.3.6 Herbivore activity

The most commonly observed activities carried out by herbivores at the study waterholes (Figure 4.10), were drinking (75.95%), cooling (8.08%), feeding/socialising (6.04%), and wallowing (3.05%). A total of 19.71% visits were categorised as unknown because activity could not be established due to a lack of clarity from photographs taken.

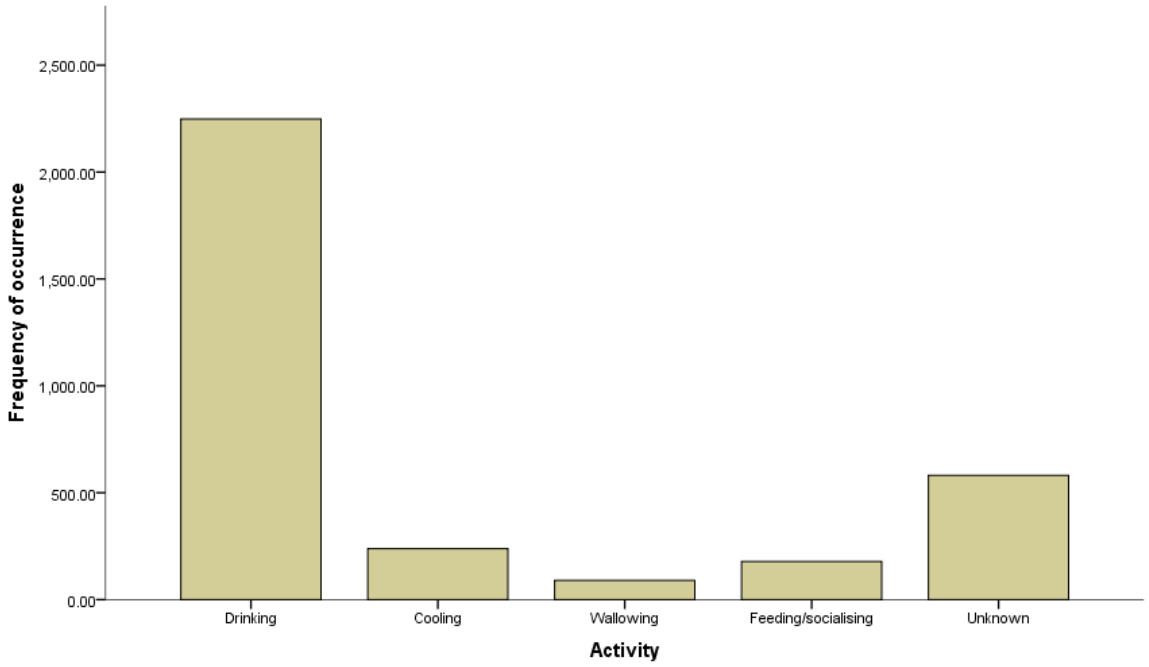

Figure 4.10: Frequency of herbivore activities for waterholes investigated.

All species were most commonly observed drinking (Figure 4.11); however, certain species showed a tendency for activities such as cooling and wallowing, whereas others did not. The highest incidence of cooling was attributed to elephants followed by warthog. Species observed wallowing included black rhino, elephant and warthog. Impala had the highest incidence of feeding/socialising. The only activity observed for duikers, white rhino and wildebeest was drinking.

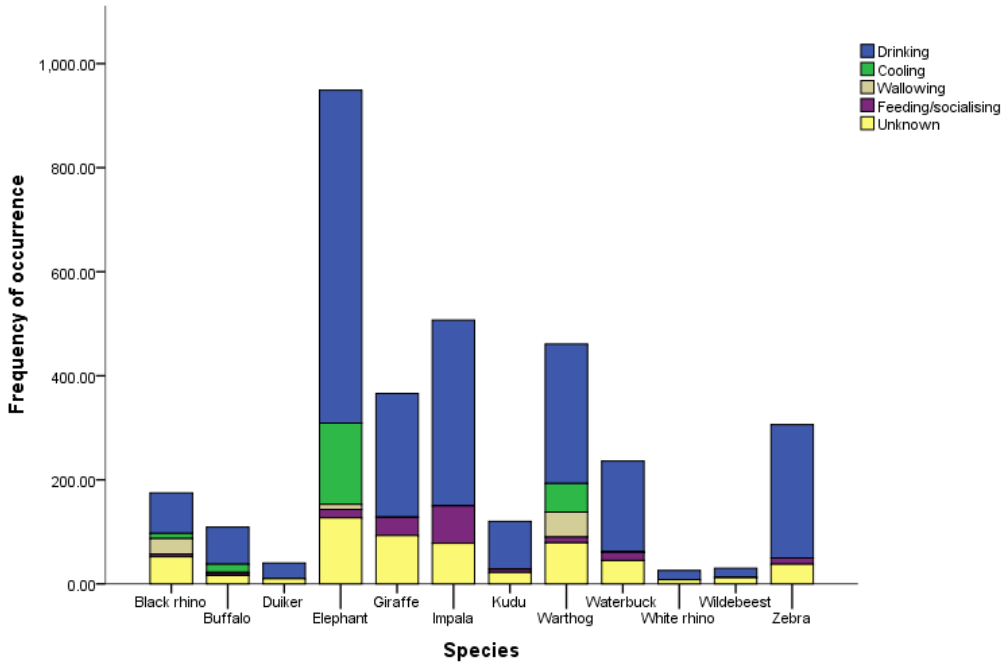

Figure 4.11: Representation of different activities for the study herbivore species.

Figure 4.12 shows the mean duration of activities for individuals and combined activities that occurred at waterholes. Visits with a combination of activities took longer on average than those in which just one activity was recorded. Feeding/socialising was the longest activity, both as a single activity, and when in combination with drinking. Combinations of three activities that included drinking, cooling and wallowing had the second highest mean duration. The shortest visits were associated with activities that could not be identified.

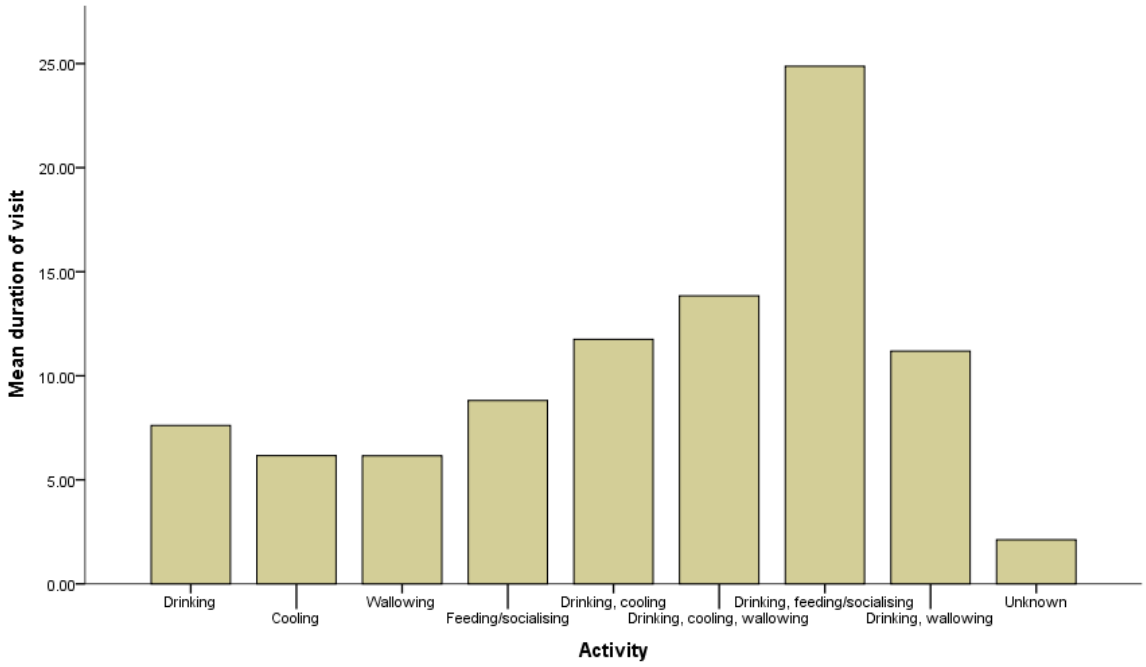

Figure 4.12: Mean durations of visits by activity category and combinations of activity categories for herbivore species studied.

The frequency of each activity per waterhole type per day was calculated (Figure 4.13). Since activities more often than not occurred together, they were combined to provide a comprehensive overview. Drinking was the most frequently occurring activity followed by cooling at all waterhole types. Feeding or socialising occurred more frequently than wallowing at pans, reservoirs and troughs, but was the least frequently occurring activity at earth dams.

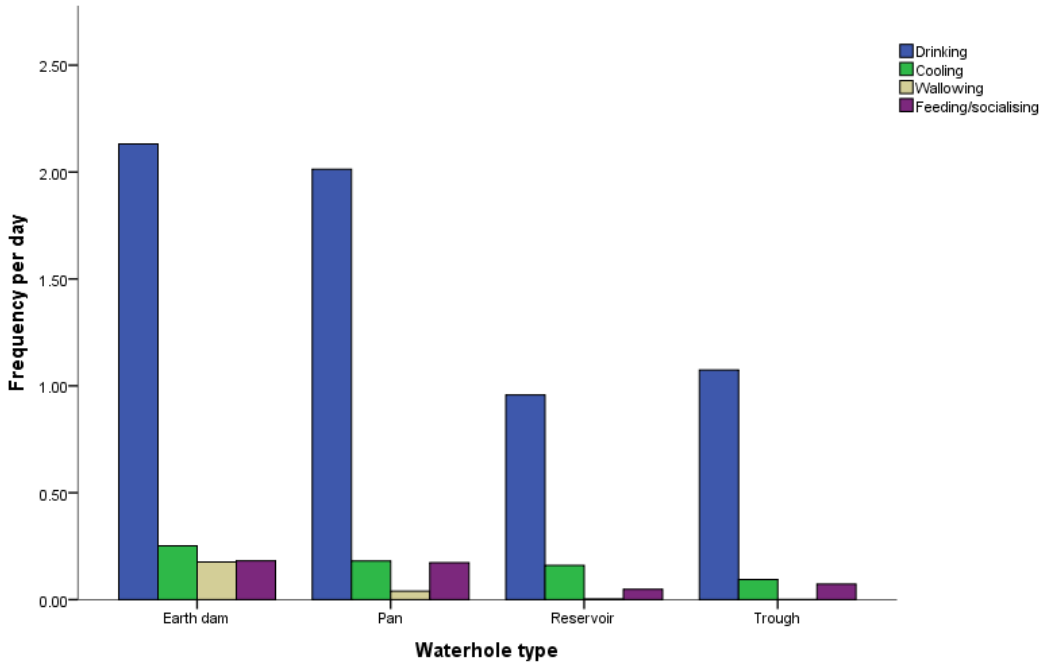

Figure 4.13: Frequencies of different activities per waterhole type.

4.3.7 Species electivity of waterholes

Using Jacob's Index (Figure 4.14), species electivity of waterholes was considered in terms of selection for or against the different waterhole types by the studied herbivore species. There was no significant variation in Jacobs Index between different waterhole types (x^2=7.37, df=3, *p*=0.06).

Earth dams were selected for by black rhino, buffalo, elephant, giraffe, warthog, waterbuck and zebra. Black rhino, buffalo, elephant, warthog, wildebeest and zebra selected for pans. Troughs were selected for by buffalo, duiker, elephant, giraffe, white rhino and zebra. Reservoirs were selected for by buffalo, elephant and giraffe, making reservoirs the least preferred waterhole type by most species.

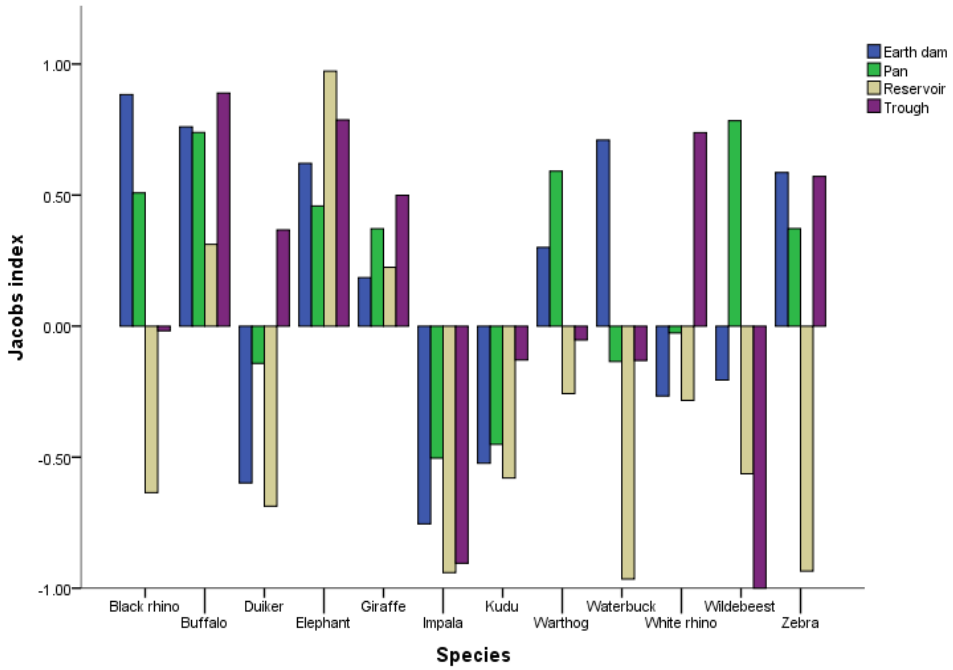

Figure 4.14: Selection for or against waterhole types by herbivore species studied. Positive values indicate selection for and negative values indicate selection against.

4.4 Discussion

This chapter focussed on herbivore utilisation of the different waterhole types, with particular emphasis on variation between waterholes as a precursor to investigating the relative impact that the study herbivores have on habitat integrity around the study waterholes.

4.4.1 Camera traps

Camera traps are commonly used to monitor waterholes remotely making them invaluable tools for collecting data when a number of sites need to be observed. While some studies have found camera traps to be effective and successful tools (Tobler *et. al.* 2008), others have found bias in data capture with strong positive correlations found between species body mass and effective detection distance (Rowcliffe *et. al.* 2011). With this in mind, future investigations are recommended to determine margins of error per species with regard to their detectability at various distances.

4.4.2 Visitations

The number of herbivores accessing the different waterhole types influences the impact that artificial waterholes have on habitat integrity. Increased feeding, damage and trampling is associated with increased numbers of individuals (Thrash 2000; Smit *et. al.* 2007). The waterhole type with the greatest number of visits per day was earth dams, followed by pans, troughs and reservoirs with the fewest number of visits per day. When considering daily numbers of individuals visiting the waterholes, earth dams had the highest numbers, followed by pans, troughs and reservoirs.

Patterns of waterhole utilisation observed for prey and predators were in accordance with findings by Ayeni (1975) and Hayward & Hayward (2012), who suggest that prey utilisation periods occur outside predator utilisation periods. However, Valeix *et. al.* (2007), reports that elephant utilise waterholes more frequently at dawn and dusk, which was not found to be the case in this study. Despite patterns of utilisation by prey indicating predator avoidance in other studies (Hayward & Hayward 2012), numbers of visits per day by predators was not statistically correlated with number of visits per day by prey species in this study. This suggests that predator utilisation of waterholes at the study site is not a significant factor contributing towards the potential influence that artificial waterholes and associated herbivores have on habitat integrity.

Duration of visit influences herbivore impact on habitat integrity, as more time spent at waterholes results in more time spent feeding and trampling in the area (Thrash 2000). The longest durations of herbivore visits in this study were associated with reservoirs. This can be attributed to elephants making up the greatest proportion of visits to reservoirs. Mean duration of visits to earth dams, pans and troughs did not vary substantially and were all within one minute of each other.

4.4.3 Species diversity

Species diversity for the various waterhole types showed which waterholes were utilised by the greatest number of herbivore species based on total number of visits. This allows for the assessment of waterhole design as an indicator of waterhole value, bearing in mind that not all waterhole types facilitate all species. Species diversity was greatest at earth dams and pans, followed by troughs. Reservoirs had a relatively low diversity score attributed to their structure. Reservoirs have high sides and restrict access to smaller species. Restriction of access is noticed when looking at the proportions of visitations per species to reservoirs, with elephant and giraffe (Figure 4.15) having exclusive access due to their ability to reach over the high sides of reservoirs. Similar diversity values for earth dams, pans and troughs suggest that diversity was not dependent on waterhole type, but to accessibility.

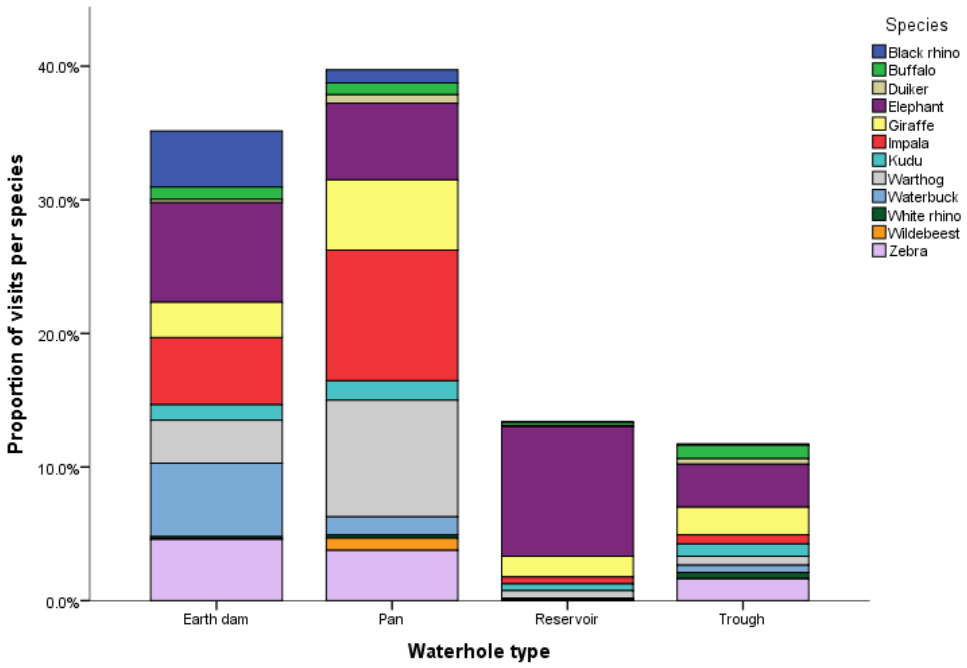

Figure 4.15: Graph showing proportions of total visits to the different waterhole types by the different herbivore species studied.

4.4.4 Diet

It was hypothesised that greater numbers of grazers would correlate with lower veld condition scores, and that greater numbers of browsers would correlate with higher disturbance to woody species. To test this, numbers of individuals from the different foraging categories (browsers, grazers and mixed feeders) visiting the different waterhole types, were compared. Browsers were the least represented foraging category at earth dams, pans and troughs. A reason for low browser representation could be that they are less dependent on water than grazers are (Smit *et. al.* 2007; Hayward & Hayward 2012). Grazers and mixed feeders have higher water requirements associated with the digestion of grasses (Valeix *et. al.* 2007; Hayward & Hayward 2012) and frequently visit waterholes. Mixed feeders (represented by two species) were represented the most at the majority of waterhole types, with the exception of earth dams, where grazers were most represented. The two species of mixed feeders in this study were elephant and impala, and being the most prevalent species in this study, contribute towards the high prevalence of mixed feeders at waterholes. Grazers were the most common foraging category in terms of number of species and were accordingly prevalent at earth dams, pans and troughs. At reservoirs grazers were less abundant than browsers, which can be explained by the difficulty of access to reservoirs experienced by most species. Further to this, habitat requirements vary between species, with variations in typical habitat being associated with the different waterhole types and influencing the prevalence of different foraging strategies.

Foraging strategy was associated with duration of visit to waterholes, with the longest mean duration of visit associated with mixed feeders, followed by browsers and grazers associated with the shortest mean duration of visit. These results however, are considered inconclusive due to the potentially confounding influence of group size as elephant and impala (mixed feeders) had the largest mean group sizes. Since group size is significantly correlated with duration of visit, it is more than likely attributed to the long mean duration of visit associated with mixed feeders.

4.4.5 Group size and herd type

Group size was not a determining factor for waterhole type or waterhole size selection. There was, however, a significant relationship between group size and species visiting, with certain species having larger groups sizes and others smaller group sizes. This suggests that group size was not dependent on characteristics associated with the different waterhole types, but rather on the species that the group was composed of. Previous studies suggest that herding behaviour including herd size is correlated with perceived risk of predation (Morrell *et. al.* 2011), and that the presence of predators in an area may influence variation in group size of prey species; however, Valeix *et. al.* (2009) found predation risk was not a strong factor influencing group size, suggesting instead that a number of other factors that influence group size (including variations in forage availability and habitat type) obscure the effects of predator avoidance (Creel & Winnie 2005).

Sexual dimorphism in elephants leads to variation in foraging habits for bulls and cow, and subsequently elephant herd types (Shannon *et. al.* 2006). With regard to buffalo, different herd types exhibit different movement patterns, with breeding herds travelling longer daily distances than bachelor herds (Hay *et. al.* 2008). While breeding herds were on average larger than bachelor herds (Figure 4.16), their transient nature within the study site may limit their impact on habitat integrity, compared to the more sedentary bachelor herds. With this in mind, variation in visitations by different herd types for elephant and buffalo were examined.

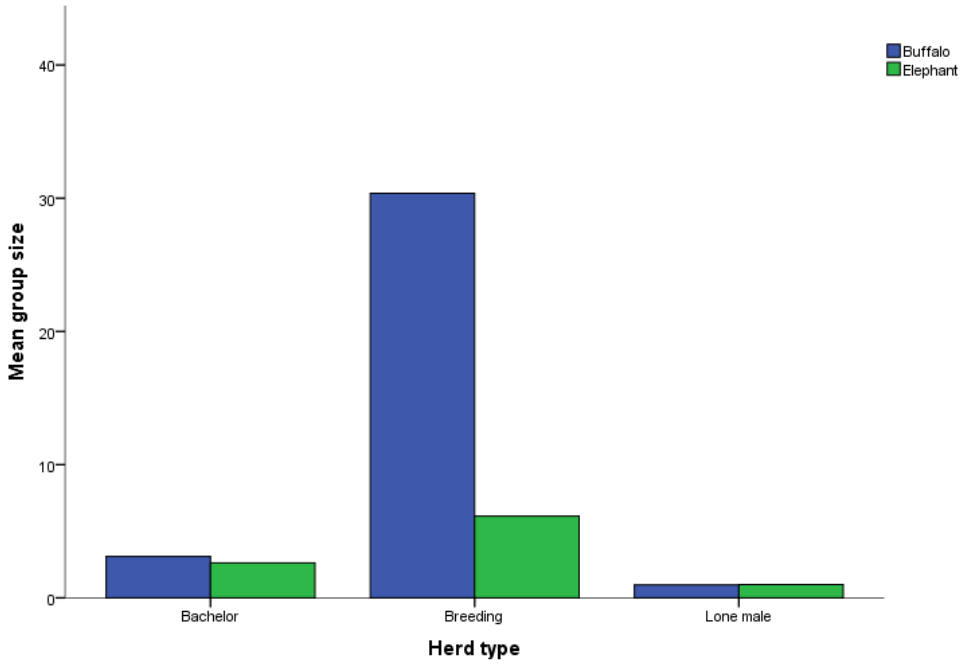

Figure 4.16: Mean group size of each herd type for buffalo and elephants observed at the different waterhole types.

Reservoirs had the lowest occurrence of buffalo visits due to the difficulty associated with accessing water in them. All buffalo herd types were most common at troughs, followed by pans for breeding herds; however, bachelor herds and lone males visited pans and reservoirs least. These findings suggest that while breeding herds favoured pans, bachelor herds and lone males avoided them in favour of earth dams and troughs.

The feeding behaviour of male elephants (associated with bachelor herds), has a greater impact than the feeding behaviour of females (associated with breeding herds). Males have destructive feeding habits, including debarking, uprooting of trees, and breaking of stems (Shannon *et. al.* 2006). The highest number of bachelor herds of elephant was observed at earth dams, followed by pans, reservoirs, and troughs. In this study, bachelor herds were the least frequently occurring herd type at all waterhole types, with breeding herds being the most common at reservoirs and troughs. Lone males were most common at earth dams and pans. This suggests that disturbance to woody species should be greater at earth dams and pans, compared to reservoirs and troughs.

Reasons for variations in waterhole type selection for different herd types could be related to their forage requirements, with bachelor herds and lone male buffalos having a greater tendency to select habitats which provide more forage compared to habitats selected by breeding herds (Hay *et. al.* 2008). Elephant bulls are larger than elephant cows and have a greater tendency toward low quality, bulk feeding (Shannon *et. al.* 2006). This allows elephant bulls to exploit a wider range of habitats, compared to elephant cows that are limited by forage quality (Shannon *et. al.* 2006).

Breeding herds of both buffalo and elephant spent on average longer times at waterholes than bachelor herds or lone males. This is likely due to the greater herd sizes associated with breeding herds, resulting in a strong correlation between group size and duration of visit. Associated with this is evidence that male buffalo and elephants spend more time feeding (Shannon *et. al.* 2006; Hay *et. al.* 2008) and less time at waterholes as a result of reduced freedom in their time budgets.

4.4.6 Herbivore activity

All herbivore species investigated utilised waterholes in this study for drinking; however, only black rhino, buffalo, elephant and warthog were observed cooling. Black and white rhino, elephant and warthog wallow (Waldram *et. al.* 2008); however, in this study white rhino did not wallow. This may be due to white rhino predominantly using pans and troughs; (Figure 4.15) whereas the majority of wallowing occurred at earth dams. Instances of wallowing at pans and reservoirs were associated with warthog utilising mud-wallows created by overspill. These mud-wallows were considered too small for larger species such as white rhino.

The longest mean duration of visits to waterholes was associated with drinking, feeding/socialising, and the largest group sizes (Figure 4.17), suggesting that feeding/socialising at a waterhole occurs while animals wait to drink. As expected, visits in which more than one activity occurred also took longer.

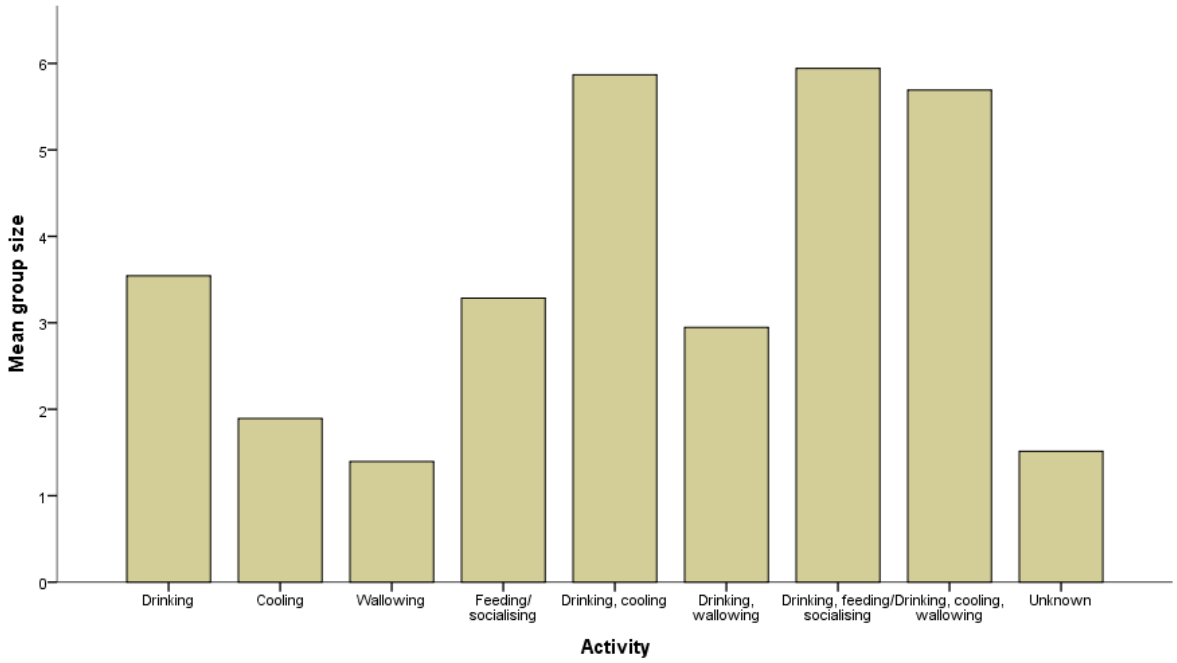

Figure 4.17: Mean group sizes for the study herbivores associated with the different activity categories observed at the different waterhole types.

4.4.7 Species electivity of waterholes

No significant variation was found for specific waterhole types when considering species electivity, suggesting that waterhole type preference is species dependent; herbivores do not exhibit preferences for a particular waterhole type. Variation in preference between waterhole types per species was not tested due to small sample sizes of data split per species. An additional factor influencing species waterhole preference, but not investigated in this study is perceived predation risk (Hayward & Hayward 2012). The risks associated with drinking may vary between individual waterholes regardless of waterhole type. For example, in the case of giraffe, risk is associated with the density of woody vegetation with open scrub and woodland perceived as relatively low risk (Thaker *et. al.* 2011). Some species of ungulate are also known to avoid waterholes following visits by humans (Wakefield & Attum 2006) and such waterholes may be selected for or against depending on the numbers of visitations by humans. Alternatively, waterholes may be selected for based on their proximity to preferred habitat types, as habitat and forage requirements are known to influence herbivore distribution (Ferrar & Walker 1974).

4.5 Conclusions

This chapter aimed to establish variation in patterns of herbivore utilisation for the different waterhole types related to the potential herbivore impact on habitat integrity around waterholes. Earth dams were the busiest waterholes in terms of both number of species visiting per day and number of individuals visiting per day. Animal species diversity was lower at earth dams compared to pans, but only by a slight margin. Earth dams were also selected for by the greatest number of species. In addition to this, earth dams had the highest occurrences of wallowing and cooling. It is evident that earth dams are the most utilised waterholes at the study site. Reservoirs are considered the least utilised waterhole type due to their inaccessibility to most species, resulting in lower visitation rates, and low occurrence of activities other than drinking.

If impact of artificial waterholes is dependent on herbivore utilisation (Thrash *et. al.* 1995; Smit *et. al.* 2007) then, based on the greatest number of herbivores utilising a waterhole, earth dams have the greatest impact on habitat integrity. Reservoirs, with the lowest number of herbivores utilising them, have the least impact on habitat integrity. Pans had a similar rate of visitation to earth dams in terms of numbers of species and individuals visiting them, and therefore can also be expected to have a relatively high impact on surrounding habitat integrity. Visitation rates to troughs were similar to that of reservoirs, resulting in a lower impact on habitat integrity than earth dams and pans.

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Chapter 5 : The impact of artificial waterholes on habitat integrity

5.1 Introduction

Waterholes are widely reported to be areas of increased activity for herbivores and the area surrounding a waterhole is thought to be highly impacted on by grazing, browsing and especially trampling (Smit *et. al.* 2007). It is suggested that areas in the immediate vicinity of waterholes are more significantly impacted on by animals than areas further away. Vegetation quality is reduced and soil is compacted, resulting in vegetation loss during the dry season (Thrash *et. al.* 1995; Thrash 2000). Areas adjacent to waterholes are referred to as 'sacrifice' areas (Thrash *et. al.* 1995). It is suggested that impacts to the herbaceous and woody layers decrease with increasing distance from waterholes (Thrash *et. al.* 1995; Thrash 2000; Brits *et. al.* 2002; Smit *et. al.* 2007; Chamaillé-Jammes *et. al.* 2009). This is consistent with the piosphere model which states that animal impacts are concentrated around waterholes resulting in the spatial distribution of animal impacts being organised along a utilisation gradient (Thrash *et. al.* 1995; Thrash 2000; Brits *et. al.* 2002; Chamaillé-Jammes *et. al.* 2009).

When considering the impact of artificial waterholes on the herbaceous layer alone, Thrash (2000) concludes that once all grazeable areas are within reach of the most water dependent herbivores, the addition of more waterholes does not affect rangeland condition as much as other factors such as stocking rates and rainfall. This emphasises the importance of managing stocking rates and considering the effects of rainfall (Thrash 2000). This was demonstrated in Klaserie during a drought period in the early 1980s where excessive waterholes allowed stocking rates to increase – when rainfall decreased, there wasn't enough forage and populations struggled to survive (Owen-Smith 1996).

The impact on woody species in terms of distance from water shows that disturbance is more noticeable closer to water sources (Brits *et. al.* 2002; Chamaillé-Jammes *et. al.* 2009). Brits *et. al.* (2002) found shrub density increased with increasing distance from water. Chamaillé *et. al.* (2009) also found woody cover to be reduced closer to water. Reduced woody plant density in the immediate vicinity of a waterhole is likely to be caused by trampling which has a negative impact on seedling survival (Chamaillé-Jammes *et. al.* 2009). It was further reported that although the sacrifice area was just a few hundred metres wide in various studies, there was a high utilisation zone of up to 2.8 km around waterholes. Impacts in the high utilisation zone are mostly caused by large herbivores (Brits *et. al.* 2002; Chamaillé-Jammes *et. al.* 2009).

This chapter explores variation in vegetation for different artificial waterhole types and whether distance from water has an effect on habitat integrity.

5.2 Methodology

Data was collected from four line transects placed in the four cardinal directions around each of the different study waterholes (Figure 5.1). Along each transect, five plots of ten square metres were placed at 200m, 400m, 600m, 800m and 1000m intervals from the centre of the waterhole (n=20 plots per waterhole). This allowed for assessment of vegetation at different distances from the waterholes. The locations of the plots were determined using the distance measure tool in Quantum GIS and a GPS for finding the plot locations in the field. Plot co-ordinates were recorded for the centre of each plot. At each plot the herbaceous and woody layers were surveyed. The control site was located to the West of the study site across the main R40 road. The control site was chosen due to its close proximity to the study site without being populated by herbivores.

Due to the high density of waterholes in the study site, the transects of study waterholes Singwe Big Dam and Singwe Bush Camp, Singwe Bush Camp and Leopard's View, Toni's Dam and Nyala and Nzulwini and Van Wyk's overlapped. Overlap was not significant and non-overlapping transects compensated for any effects caused by this. Further to this, an

additional calculation considering not just distance of vegetation plot from a study waterhole, but also minimum distance from all waterholes (including non-study waterholes), was included. This calculation was particularly valuable due to the high density of waterholes on the reserve (Figure 3.1).

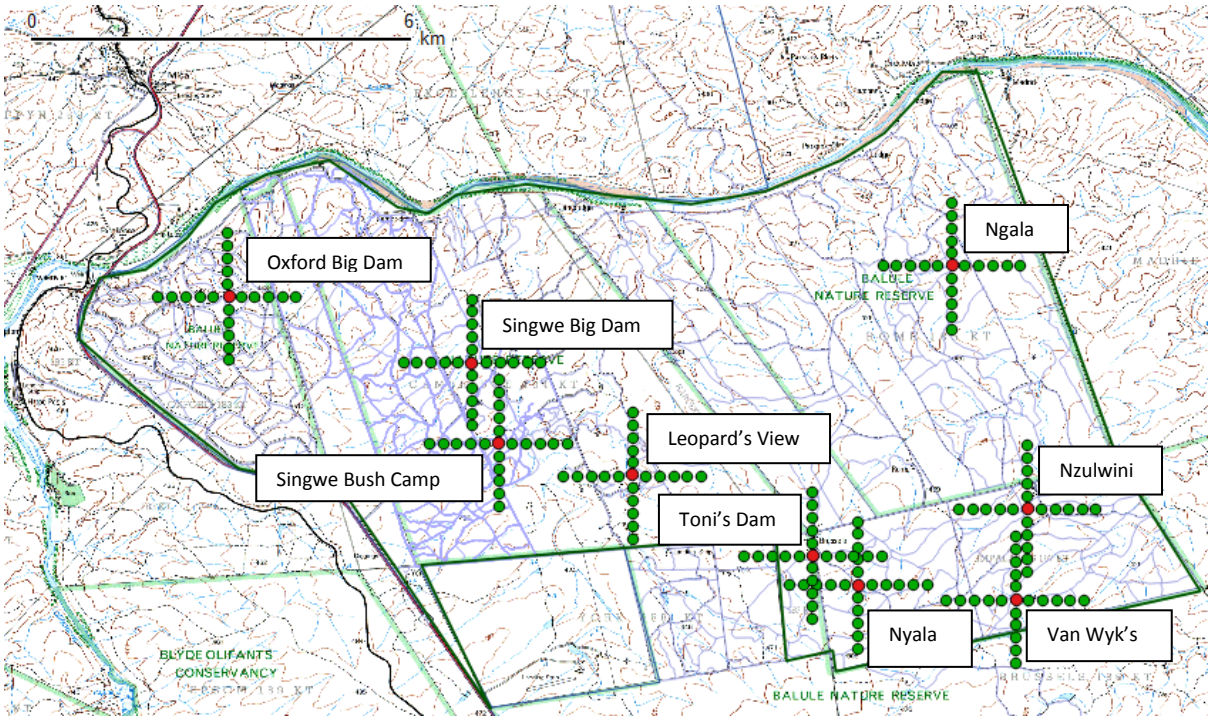


Figure 5.1: Map of the study area with red dots indicating the waterholes and blue dots indicating plots for the four transects placed at each waterhole.

Data collection at vegetation plots was carried out during the wet season (Table 5.1). A control site was identified and placed outside the reserve in an area with no waterholes or herbivores. Ten control plots were placed at the control site and surveying was done during the same time period as for the plots in the study area (Table 5.1).

Table 5.1: Start and end dates vegetation surveys.

Waterhole		
	Start date	**End date**
Leopard's view	06.12.13	09.12.13
Ngala	04.01.14	05.01.14
Nyala	03.12.13	16.01.14

Nzulwini	13.12.13	24.12.13
Oxford	10.12.13	12.12.13
Singwe Bush Camp	14.12.13	20.12.13
Singwe Big Dam	14.12.13	20.12.13
Toni's	02.12.13	03.12.13
Van Wyk's	21.12.13	22.12.13
Control	18.12.13	18.12.13

Data were collected from both the herbaceous and woody layers. The herbaceous layer was assessed using veld condition scores and the woody layer by determining woody species height, diversity and level of disturbance. In addition to this, percentage coverage estimation was done for the herbaceous layer, woody layer and bare ground.

5.2.1 Herbaceous layer

As stated in chapter 3, the Ecological Index Method (Vorster 1982; Van Oudtshoorn 2012) was used to assess veld condition of the herbaceous layer. This was done using the step point method. One hundred steps points were recorded across each plot in a grid pattern.

The herbaceous vegetation was differentiated into ecological status categories (Van Rooyen *et. al.* 1996; Van Oudtshoorn 2012). Forbs, weeds and invaders were included in the analysis because they have some nutritional value (Treydte *et. al.* 2011). Forbs were given a low score as an increase in forb abundance indicates lower pasture quality (Nangula & Oba 2004). Table 5.2 shows the Ecological status classes of grasses with their corresponding scores.

Table 5.2: Definitions and veld condition score equations for herbaceous species recorded in this study (Van Rooyen *et. al.* 1996).

Ecological status class	**Definition**	**Equation**	**Species**
Decreaser	A grass species which is dominant in good veld	% D * 10	*Cenchrus ciliarus* *Digitaria eriantha*

	which is well managed, but decreases when veld is mismanaged, overgrazed or under-utilised.		*Panicum maximum*
Increaser I	A grass species which increases when veld is selectively utilised or under-utilised.	% I1 * 7	*Cymbopogon caesius* *Hyparrhenia hirta* *Melinis nerviglumis*
Increaser II	A grass species which is dominant in poor veld and increases as a result of overgrazing.	% I2 * 4	*Aristida adscensionis* *Aristida congesta* *Aristida diffusa* *Aristida scabrivalvis* *Bothriochloa radicans* *Chloris virgata* *Enneapogon cenchroides* *Eragrostis lehmanniana* *Eragrostis patentipilos* *Eragrostis rigidior* *Eragrostis superba* *Eragrostis trichophora* *Heteropogon contortus* *Melinis repens* *Perotis patens* *Pogonarthria squarrosa* *Schmidtia pappophoroides* *Setaria pumila* *Sporobolus panicoides* *Tragus berteronianus* *Tricholaena monachne* *Urochloa mosambicensis*

Increaser III	A grass species which is dominant in poor veld and increases as a result of heavy overgrazing.	% I3 * 1	*Aristida meridionalis*
WIF	Weeds, invaders and forbs.	% F * 1	Forbs

5.2.2 Woody layer: height

Woody species structural terminology is according to Edwards (1983) and each woody plant species identified was placed into one of five height class categories (adapted from Edwards 1983) and scored accordingly (Table 5.3). Height of woody species was determined using a 1.5m stick as a frame of reference. If woody species were measured to be within a particular height range, the corresponding score was given.

Table 5.3: Height categories of woody species with corresponding height classes they represent and allocated category scores.

Category	**Height Range**	**Score**
1	<0.5m	0.5
2	0.5m – 1.5m	1.0
3	>1.5m – 3.0m	1.5
4	>3.0m – 4.5m	2.0
5	>4.5m	2.5

5.2.3 Woody layer: disturbance

Disturbance was assessed according to perceived damage to woody plant species. Damage was categorised as bent branches, broken branches, damage to trunk, pushed over, and dead (Table 5.3). A negative score was attributed to each of these damage categories,

depending on the degree of the damage (Table 5.3). The extent of each damage type was quantified and scored according to whether it was perceived as low, medium or high.

Table 5.4: Types of damage attributed to trees and shrubs with corresponding scores based on the degree of damage.

Damage	**Low**	**Medium**	**High**
Bent branches	-0.1	-0.2	-0.3
Broken branches	-0.3	-0.4	-0.5
Damage to trunk	-0.6	-0.7	-0.8
Pushed over	0	-0.8	-0.9
Dead	-2		

Between 0% and 33% of bent branches resulted in a low impact score, between 33% and 66% resulted in a medium impact score, and greater than 66% of bent branches resulted in a high impact score. The same percentiles were used for broken branches but with broken branches eliciting a lower negative score than bent branches due to the higher impact attributed to this type of damage. Damage to trunks also used these percentiles, but with reference to the percentage of the circumference of the trunk that had been damaged. A high impact score was attributed to a 'pushed over' tree if it was parallel to the ground or if roots were showing. A medium impact score was attributed if it was clear that a tree had been pushed over, but not severely. Low impact scores were not attributed for this damage category as it was not clear that a tree simply growing at an angle had been actively damaged or not. Dead trees were given a single negative score.

All scoring was carried out by the same person to reduce inter-observer bias and to maintain consistency.

5.2.4 Woody layer: species diversity

Woody species diversity per plot was calculated using Simpson's Index of Diversity (Equation 5.1) representation of species in terms of the entire sample. Woody species were identified

to the species level except in the cases of *Commifera* spp., *Grewia* spp. and *Boscia* spp. These were identified to the genus level due to similarities between members of the group (Van Wyk & Van Wyk 2013) and for greater efficiency in the field.

Equation 5.1: (a) Simpson's Diversity (b) Simpson's Index of Diversity.

$$(a)\boldsymbol{D} = \frac{\sum \boldsymbol{n}(\boldsymbol{n}-\mathbf{1})}{\boldsymbol{N}(\boldsymbol{N}-\mathbf{1})} \qquad (b)\ \mathbf{1} - \boldsymbol{D} = \mathbf{1} - \frac{\sum \boldsymbol{n}(\boldsymbol{n}-\mathbf{1})}{\boldsymbol{N}(\boldsymbol{N}-\mathbf{1})}$$

n = total number of trees of a particular species

N = total number of trees in a sample

5.2.5 Habitat score

The savannah biome consists of a herbaceous layer and a woody layer (Mucina & Rutherford 2006). Habitat scores were determined using equations that combined data from both these layers (Table 5.5). For habitat score calculations, herbaceous and woody layer variables were standardised and VCS was multiplied by 10 to calibrate it with woody species disturbance, woody species diversity and woody species height. Doing this reduces the likelihood that VCS skews the habitat score being calculated.

Table 5.5: Equations for determining habitat scores.

Herbaceous layer	**Veld Condition Score (VCS)**		
	Increaser I = %I 1 * 7 Increaser II = % I2 * 4 Increaser III = % I3 *1 Decreaser = % D * 10 Forb = % F * 1 Miss = 0		
Woody	**Height**	**Disturbance**	**Diversity**

layer	<0.5m = 0.5 0.5m to 1.5m = 1.0 1.5m to 3.0m = 1.5 3.0m to 4.5m = 2 >4.5 = 2.5	No damage = 0 Bent Branches = -0.1 → -0.3 Broken Branches = -0.3 → -0.5 Damage to trunk = -0.6 → -0.8 Pushed over = -0.8 → -0.9 Dead = -2	Simpson's Index of Diversity = 0 - 1
Total Habitat Score = ((VCS/1000)*10) + Disturbance + Diversity + Woody species height H = VCS + Di +Si + Wsh			

5.2.6 Statistics

Table 5.6 lists the combination of statistical analyses carried out in this chapter.

Table 5.6: Statistical analyses done in Chapter 5.

Statistical test	**Variable I**	**Variable II**
	VCS	Waterhole type
	VCS	Plot
	VCS	Plot (Earth dam)
	VCS	Plot (Pan)
	VCS	Plot (Reservoir)
	Woody species height	Waterhole type
	Woody species height	Plot
	Woody species height	Plot (Earth dam)
	Woody species height	Plot (Pan)
	Woody species height	Plot (Reservoir)
	Disturbance	Woody species height
	Woody species height	Species
	Disturbance	*Grewia* spp. height
	Disturbance	*Senegalia nigrescens* height
	Disturbance	*Combretum apiculatum* height

	Disturbance	*Terminalia prunioides* height
	Disturbance	*Acacia erubescens* height
	Disturbance	*Boscia* spp. height
	Disturbance	*Commifera* spp. height
	Disturbance	*Dichrostachys cinerea* height
	Disturbance	Waterhole type
	Disturbance	Plot
	Woody species diversity	Waterhole type
	Woody species diversity	Plot
	Habitat score	Waterhole type
	Habitat score	Plot
	VCS	Date of data collection
	VCS	Minimum distance from water
	VCS	Minimum distance from drainage line
	VCS	Minimum distance from drainage line (Earth dam)
	VCS	Minimum distance from drainage line (Pan)
	VCS	Minimum distance from drainage line (Reservoir)
	VCS	Number of waterholes in 1 km radius
	% cover herbaceous layer	Percentage cover woody layer
	Woody species height	Minimum distance from water
	Woody species height	Number of waterholes in 1 km radius
	Woody species height	Minimum distance from drainage line
	Disturbance	Minimum distance from water
	Disturbance	Minimum distance from water (Earth dam)
	Disturbance	Minimum distance from water (Pan)
	Disturbance	Minimum distance from water (Reservoir)
	Woody species diversity	Minimum distance from water
	Woody species height	Minimum distance from water (Earth dam)
	Woody species height	Number of waterholes in 1 km radius

	Woody species height	Minimum distance from drainage line
	Habitat score	Minimum distance from water
	Habitat score	Number of waterholes in 1 km radius
	Habitat score	Minimum distance from drainage line

5.3 Results

5.3.1 Herbaceous layer

Veld Condition Score was highest at reservoirs, followed by pans, the control site, and earth dams having the lowest scores. Waterhole type was a significant factor for determining VCS (x^2=31.6, df=3, *p*=<0.01).

Plot distance from study waterhole was not a significant factor in determining veld condition score (x^2=1.857, df=4, *p*=0.76). When considering waterhole type separately, plot distance from study waterhole was also not a significant determinant of veld condition score (Table 5.7). In addition to this, there was no significant correlation between minimum distance from all water holes and VCS (r=0.105, df=189, *p*=0.16).

Table 5.7: Results of Kruskal-wallis tests carried out for VCS and plot distances from study waterhole per waterhole type.

Waterhole type	Veld Condition Score	
	Chi-square	Sig.
Earth	3.564	0.468
Pan	1.519	0.823
Reservoir	1.090	0.896

Proximity of the study waterholes to drainage lines and overall waterhole density within a one kilometre radius of study waterholes was also investigated. Proximity to drainage lines

was significant in terms of veld condition score (r=-0.252, df=179, *p*=<0.01). The relationship between waterhole distances from drainage lines for VCS indicated significant negative correlations for earth dams (r=-0.282, df=59, *p*=0.03) and pans (r=-0.366, df=59, *p*=<0.01), but not for reservoirs (r=-0.091, df=59, *p*=0.49). Waterhole density was not significant (r=-0.099, df=179, *p*=0.19).

5.3.2 Woody layer

Thirty-nine woody species were identified in the study plots (Table 5.8).

Table 5.8: Woody species identified with frequencies of occurrence across 180 plots in order of count from highest to lowest.

Common name	**Scientific name**	**Count**
Raisin bush	*Grewia* spp.	435
Red bushwillow	*Combretum apiculatum*	343
Corkwood	*Commifera* spp.	140
Sickle bush	*Dichrostachys cinerea*	86
Knobthorn	*Senegalia nigrescens*	82
Lowveld clusterleaf	*Terminalia prunioides*	80
Shepherd's tree	*Boscia sp.*	29
Bluethorn	*Senegalia erubescens*	23
Common spikethorn	*Gymnosporia buxifolia*	18
Flaky thorn	*Vachellia exuvialis*	12
White-berry bush	*Flueggea virosa*	12
Zebrawood	*Dalbergia melanoxylon*	12
Common false thorn	*Albizia harveyi*	10
Sandpaper bush	*Ehretia amoena*	10
Blue sourplum	*Ximenia americana*	9
Caterpillar bush	*Ormocarpum trichcarpum*	8
Marula	*Sclerocarya birrea*	8

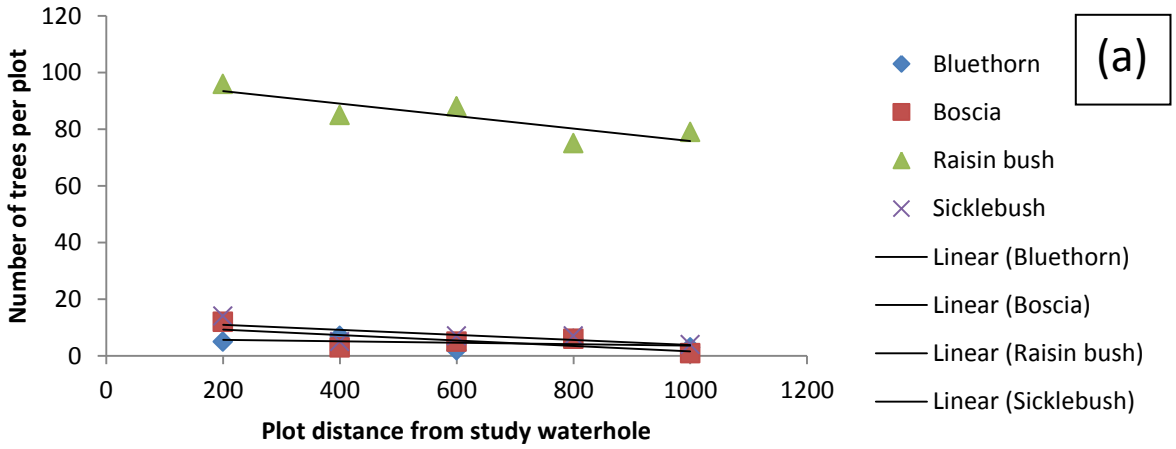
Buffalo thorn	*Ziziphus mucronata*	7
Common guarri	*Euclea undulata*	7
False marula	*Lannea schweinfurthii*	7
Apple-leaf	*Lonchocarpus capassa*	4
Leadwood	*Combretum imberbe*	4
Puzzle bush	*Ehretia rigida*	4
Broad leaved resin tree	*Ozoroa obovata*	3
Sweet thorn	*Vachellia karroo*	3
Tree wisteria	*Bolusanthus speciosus*	3
Variable bushwillow	*Combretum collenium*	3
Green thorn	*Balanites maughamii*	2
Jacket plum	*Pappea capensis*	2
Lowveld milkberry	*Manilkara mochisia*	2
Russet bushwillow	*Combretum hereroense*	2
Sjambok pod	*Cassia abbreviata*	2
Sour plum	*Ximenia caffra*	2
Knobbly creeper	*Combretum mossambicense*	1
Tamboti	*Spirostachys africana*	1
Weeping boer bean	*Schotia brachypetala*	1
Weeping wattle	*Peltophorum africanum*	1
White resin tree	*Ozoroa engleri*	1

Grewia spp. and *Combretum apiculatum* were the most frequently observed species at most waterholes and at the control site, but not at Toni's Dam where *Combretum apiculatum* and *Commifera* spp. were represented equally, followed by *Grewia* spp. *Grewia* spp. were the most frequently occurring species at Leopard's View, Singwe Big Dam, Singwe Bush Camp and Van Wyk's with *Combretum apiculatum* the most frequently occurring species at Ngala, Nyala, Nzulwini, Oxford and the control site. As the third most commonly recorded tree species in this study, *Commifera* spp. were in the top three for seven of the ten study sites. Of the remaining three study sites, the third most frequently occurring species was *Senegalia nigrescens* at two sites (Ngala and Nzulwini) and *Dichrostachys*

cinerea at one site (Singwe Big Dam). When waterhole types were considered, the top occurring species were *Grewia* spp. followed by *Combretum apiculatum* and *Commifera* spp. at earth dams, pans and reservoirs. At earth dams, *Commifera* spp. and *Senegalia nigrescens* frequencies were the same.

Frequencies of the eight most commonly occurring woody species were analysed since these species had sufficiently large sample sizes (more than 20 individuals). Of the waterhole types, reservoirs had the highest frequency of trees per plot with an average number of 8.1 trees per plot, followed by earth dams with 7.8, pans with 6.6, and the control site with 5.1. Though reservoirs had the highest average number of trees per plot, percentage cover was only 21.1%, which was marginally less than for earth dams, 21.5%. The lowest percent cover by woody species was observed at the control site, 13.8%, followed by pans 18.5%. Percentage cover by woody species was significantly negatively correlated with percentage cover by herbaceous species, as herbaceous cover decreased, woody cover increased (r=-0.64, df=374, p=<0.01).

Plots were placed at distances of 200m, 400m, 800m and 1000m from the study waterholes. Frequencies of *Senegalia erubescens*, *Boscia* spp., *Grewia* spp., and *Dichrostachys cinerea* were negatively associated with increasing distance of plots from study waterholes, reducing in numbers further away from water (Figure 5.2a). The opposite trend was observed for *Commifera* spp., *Terminalia prunioides* and *Combretum apiculatum* (Figure 5.2b).



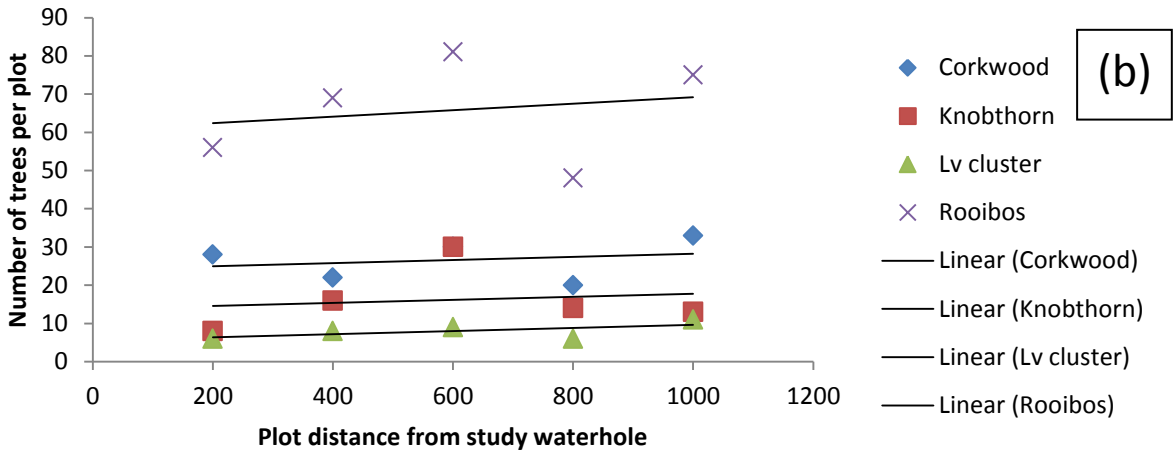


Figure 5.2: Scatter plots showing (a) the negative and (b) positive relationships between frequency of occurrence of the eight most commonly occurring woody species to plot distance from study waterhole.

The highest average frequency of all woody species was seen at plots 600m metres from study waterholes, 8.6 trees per plot. Plots situated 200m away from the study waterholes had an average of 8.1 trees per plot. At 400m there was an average of 7.2 trees per plot, at 800m 6.2, and at 1000m 7.3. Although plots at 600m had the highest average number of trees per plot, the highest percentage cover by woody species was for plots 200m from the study waterholes – 22.2%. The next highest percent coverage was at 600m – 21.5%, followed by 400m – 20.1% and 1000m – 20.1%. At 800m the average percent cover of woody species was 17.9%. The control site had both the lowest number of trees per plot with just 5.1 and the lowest percentage cover – 13.8%.

5.3.3 Woody layer: height

Waterhole types were significantly related to woody plant species heights (x^2=18.427, df=3, *p*=<0.01), with mean height of woody plant species being highest at the control site and lowest at reservoirs (Figure 5.3).

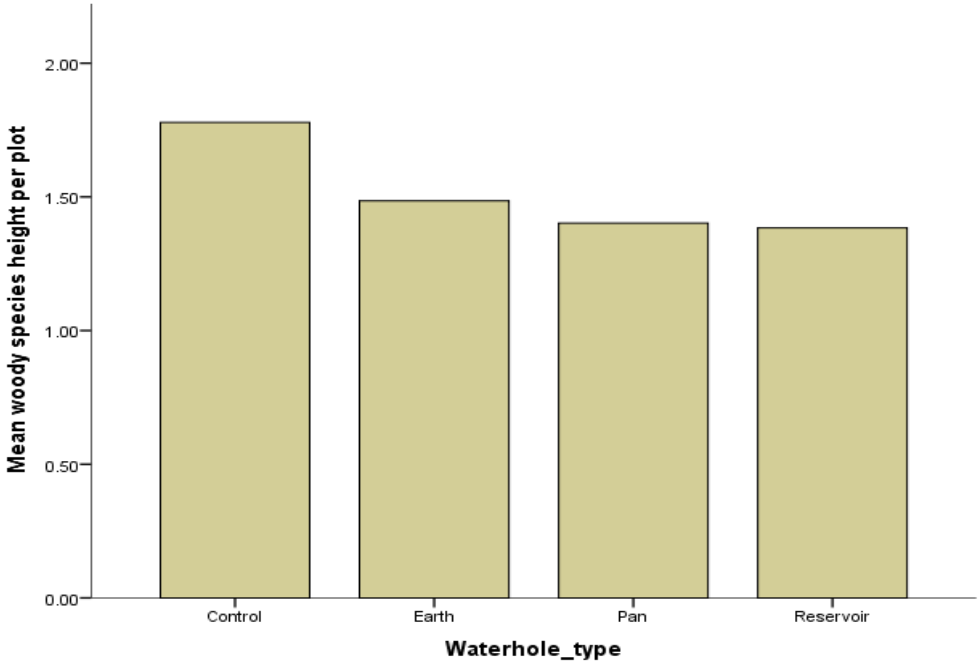


Figure 5.3: Variation in mean woody species heights by waterhole type and for the control site.

Height did not vary significantly between plots in terms of distance from study waterholes (x^2=5.883, df=4, *p*=0.21). When data was analysed per waterhole type the following results were observed for earth dams (x^2=1.047, df=4, *p*=0.90), pans (x^2=6.563, df=4, *p*=0.16) and reservoirs (x^2=6.445, df=4, *p*=0.17).

When minimum distances from study waterholes, were correlated with tree heights, there were no significant relationships (r=-0.078, df=179, *p*=0.30). No significant correlations were found when considering tree height and number of waterholes within a 1 km radius of study waterholes (r=0.073, df=179, *p*=0.33) or for tree height and minimum distances from drainage lines (r-0.105, df=179, *p*=0.16).

5.3.4 Woody layer: disturbance

Senegalia erubescens were the only species to have no individuals recorded with damage. *Senegalia nigrescens* had the least damage, with 15.85% of trees having no damage, followed by *Commifera* spp. 9.35%, *Dichrostachys cinerea* 6.98%, *Combretum apiculatum*

4.08%, *Boscia* spp. 3.45%, *Grewia* spp. 1.38%, and *Terminalia prunioides* 2.50%. The most frequent damage type recorded was broken branches for both the study sites and the control site. Bent branches were commonly observed on trees that had broken branches. No trees had damage to their trunks in the form of bark-stripping and only one of *Commifera* spp. was recorded to have bent branches, broken branches and to have been pushed over. Woody species with the highest percentage of individuals observed to have been pushed over were *Senegalia erubescens* 8.70%, *Boscia* spp. 6.90%, *Combretum apiculatum* 5.24%, and *Commifera* spp. 5.04%. All other species had less than 3% of sampled individuals pushed over and no *Dichrostachys cinerea* were recorded as pushed over. In total, 51 trees were classified as dead. Of the most frequently occurring species, *Senegalia nigrescens* had the largest percentage of dead individuals 15.85%, *Commifera* spp. 7.19%, *Grewia* spp. 3.22%, *Dichrostachys cinerea* 4.65% and *Combretum apiculatum* 0.29%. No *Terminalia prunioides*, *Senegalia erubescens* or *Boscia* spp. were recorded as dead.

Disturbance to individual trees was determined by allocating a negative score to each damage type with additional variation in score depending on the degree to which the damage was observed. The score for each type of damage observed on an individual was summed and inverted. Higher values indicate higher levels of disturbance. When considering overall disturbance for the most frequently occurring woody species in this study (Figure 5.4), the greatest disturbance was seen in *Senegalia nigrescens*, with a mean disturbance score of 0.57. The lowest disturbance score was associated with *Terminalia prunioides* with a score of 0.35.

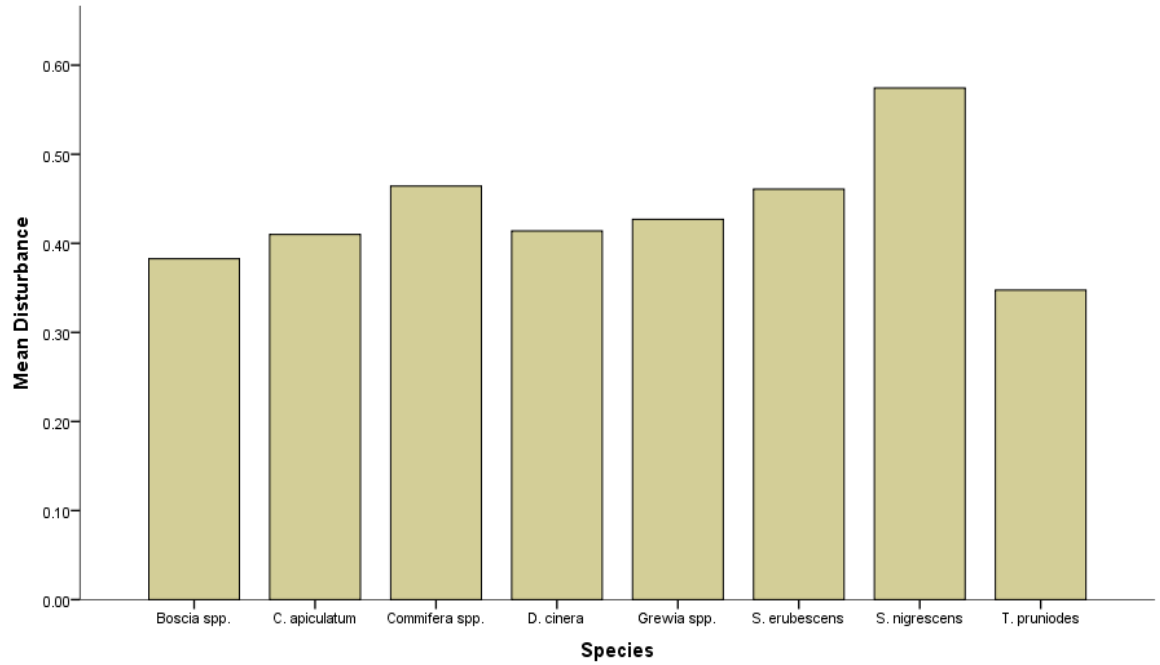


Figure 5.4: Disturbance observed for the most frequently occurring woody species recorded in the study plots.

A significant relationship was found between height classes and disturbance (x^2= 82.34, df=4, *p*=<0.01). Some trees were not represented in all height classes. A significant relationship was found between species and height class (x^2=1247.50, df=7, *p*=<0.01), which may lead to species being a confounding variable when using community structure to explain variation data if species determines height, and not herbivore influence. With this in mind, the relationship between height class and disturbance was analysed for woody plant species. The explanatory power of height on disturbance varied depending on the woody species. For *Grewia* spp. (x^2= 14.31, df=3, *p*=<0.01), *Senegalia nigrescens* (x^2= 18.81, df=4, *p*=<0.01), *Combretum apiculatum* (x^2= 69.08, df=3, *p*=<0.01) and *Terminalia prunioides* (x^2= 8.67, df=3, *p*=0.03) disturbance varied significantly with height. Disturbance for *Senegalia erubescens* (x^2= 3.42, df=2, *p*=0.81), *Boscia* spp. (x^2= 0.99, df=1, *p*=0.32), *Commifera* spp. (x^2= 7.76, df=4, *p*=0.10) and *Dichrostachys cinerea* (x^2= 3.02, df=2, *p*=0.22) did not vary significantly with height.

When examining height class to type of disturbance, individuals that were less than 0.5m in height had the least damage, with 62% of individuals in this height category having no

damage. Trees between 0.5m and 1.5m had 11% damage, and those between 1.5m and 3m 2% damage. Individuals between 3m and 4.5m, and over 4.5m had no individuals recorded to have no damage. Broken branches were the most common form of impact for most height classes, with the exception of those less than 0.5m. Trees over 4.5m had the largest percentage of individuals that were recorded as dead 13.64%, between 3m and 4.5m 1.32%, 1.5m and 3m 1.16%, and 0.5m and 1.5m 1.38%. No trees less than 0.5m were recorded as dead.

There was a significant relationship between waterhole type and disturbance (x^2=12.19, df=3, *p*=0.01). The greatest mean disturbance was seen at earth dams, followed by pans, and reservoirs. The lowest mean disturbance was observed at the control site (Figure 5.5).

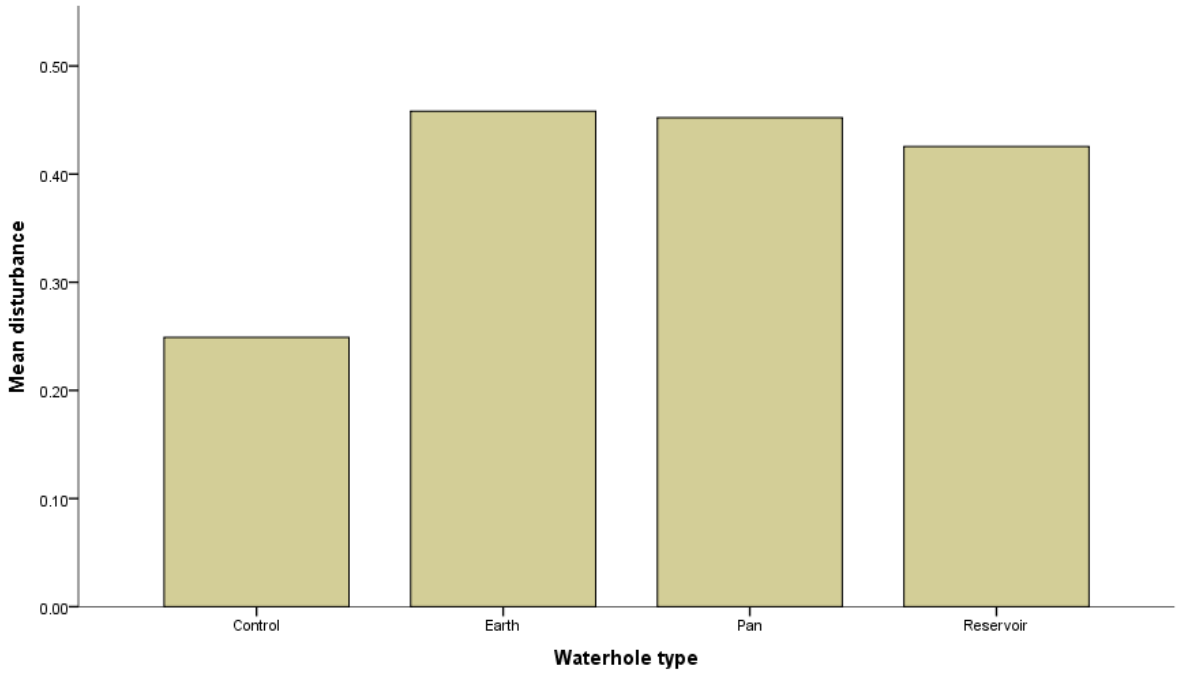


Figure 5.5: Mean disturbance observed for the different waterhole types.

The most common type of disturbance was broken branches for all waterhole types. A total of 90% of trees at reservoirs were recorded to have broken branches, 89% at earth dams, 85% at pans, and 71.0% at the control site. Earth dams had the highest occurrence of dead trees with 5.5%, compared to 3.8% at pans and 2.3% at reservoirs. No trees in the control site were recorded as dead. At both pans and reservoirs, the most frequently occurring

damage type after broken branches, was bent branches with 8.9% at reservoirs and 6.9% at pans. At earth dams 5.3% of trees were recorded to have bent branches. No trees at the control site had bent branches. The highest proportion of trees recorded as pushed over was pans 6.1%, followed by reservoirs 4.3%, earth dams 2.3% and the control site 2.0%. The control site had the highest proportion of trees recorded to have disturbance scores of 0 (no damage) 27.5%, pans 6.6%, reservoirs 3.7%, and earth dams 3.8%.

Disturbance was recorded at all distances from waterholes. No significant relationship was found between disturbance to woody species and plot distance from study waterhole (x^2=6.894, df=4, *p*=0.14). When considering disturbance for just woody plant species with distance from waterhole, there was a significant correlation between disturbance and minimum distance from waterholes (r=-0.162, df=179, *p*=0.03), the greater the distance from water, the lower the disturbance. When considering waterhole types separately, no significance was found for earth dams (r=-0.097, df=59, *p*=0.46) or reservoirs (r=-0.126, df=59, *p*=0.34). There was a significant correlation between disturbance at pans and minimum distance from water (r=-0.266, df=59, *p*=0.04).

No significant correlations were found between disturbance and number of waterholes within a 1 km radius of the study waterholes (r=-0.045, df=179, *p*=0.55) or between disturbance and minimum distance from drainage lines (r=-0.123, df=179, *p*=0.10).

5.3.5 Woody layer: species diversity

There was little variation in species diversity for the different waterholes type (Figure 5.6) (x^2=1.42, df=3, *p*=0.70). The highest mean species diversity was observed at earth dams, followed by pans, reservoirs and the control site having the lowest species diversity.

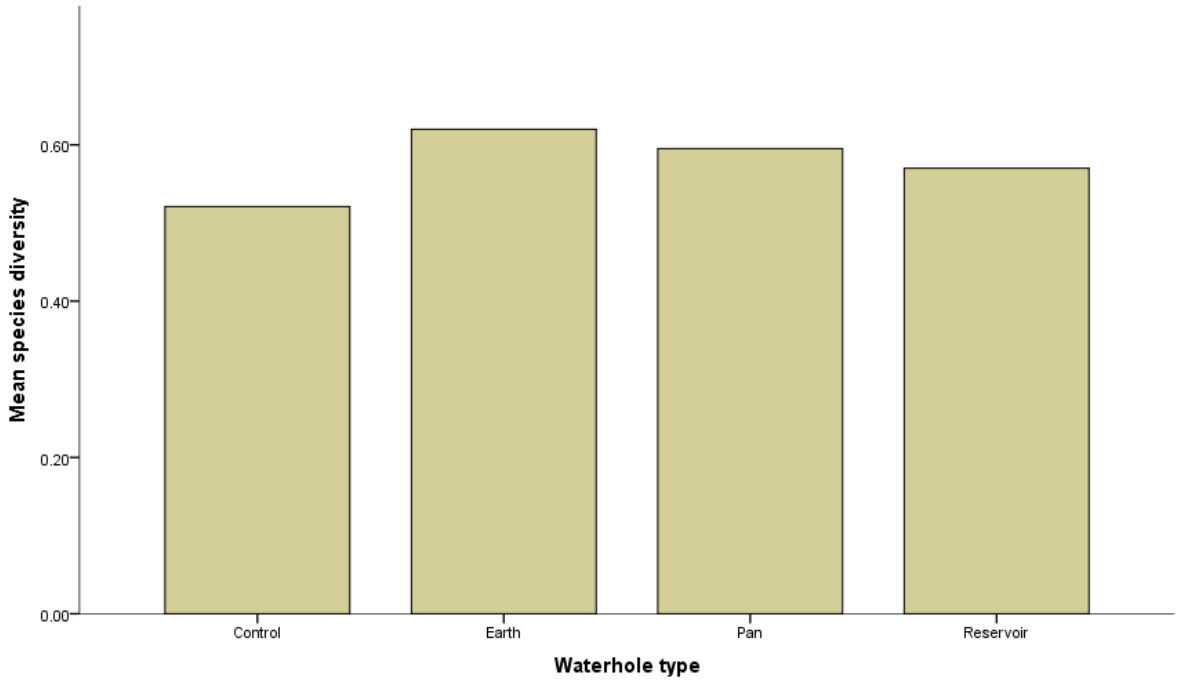


Figure 5.6: Mean species diversity for the different waterhole types.

Species diversity relative to distance from study waterholes was examined (Figure 5.7). The greatest species diversity was observed at plots 400m from the study waterhole and the least was observed at 800m.

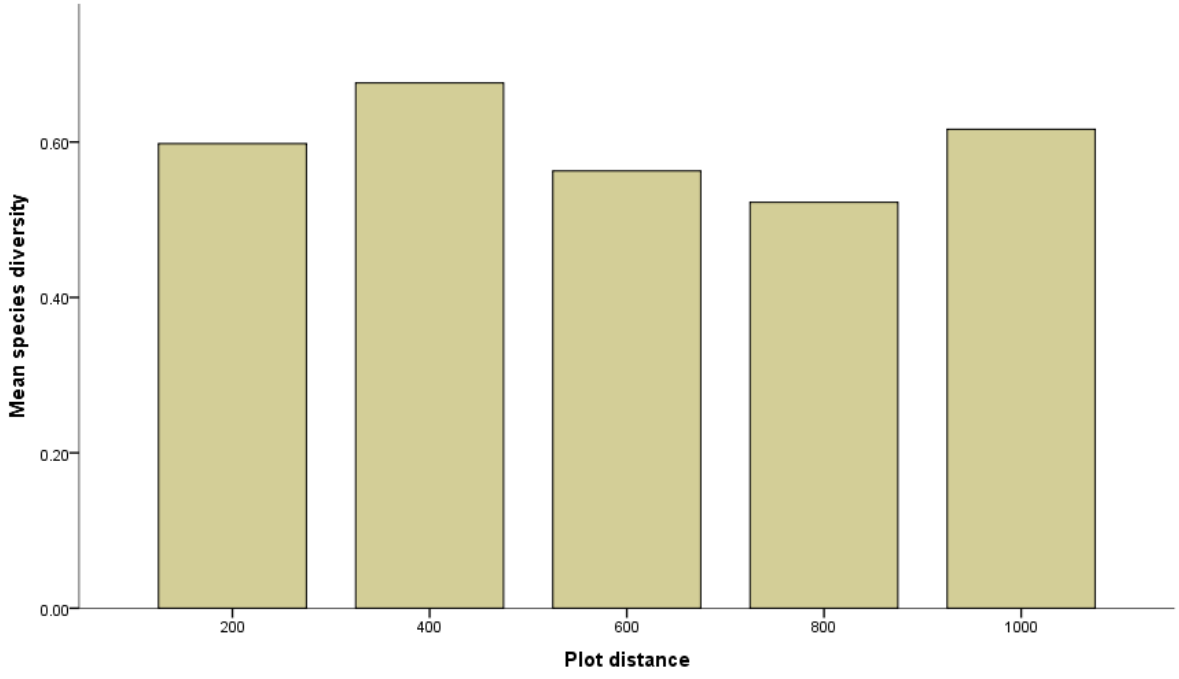


Figure 5.7: Species diversity relative to distance from study waterholes.

There was no statistical relationship between plot distance from study waterhole and species diversity (x^2=2.52, df=4, *p*=0.64). When the minimum distance from all water sources was taken into account, there was no significant correlation between minimum distance from water and species diversity (r=-0.103, df=179, *p*=0.167). When waterhole types were considered separately, a significant negative correlation was found between minimum distance to water and species diversity at earth dams (r=-0.387, df=59, *p*=<0.01).

No significant correlations were recorded when considering woody species diversity and number of waterholes within a 1 km radius of the study waterholes (r=0.025, df=179, *p*=0.74), or between species diversity and minimum distance from drainage lines (r=-0.009, df=179, *p*=0.90).

5.3.6 Habitat scores

The mean values for habitat integrity variables that contributed to the habitat score and the habitat score itself are shown in Table 5.8. The values are shown as a mean value per waterhole and per waterhole type. Habitat scores were calculated per plot.

Table 5.9: Table showing the results of habitat integrity variables at each waterhole and waterhole type as a mean value.

	VCS	Woody species diversity	Woody species height	Woody species disturbance	Habitat Score
Waterhole					
Leopard's View	0.404	0.671	11.125	-2.780	9.420
Ngala	0.356	0.554	13.800	-3.995	10.715
Nyala	0.453	0.592	8.475	-3.070	6.450
Nzulwini	0.401	0.650	12.700	-3.330	10.420
Oxford	0.238	0.694	10.975	-3.435	8.472
Singwe Big Dam	0.311	0.614	9.100	-2.440	7.588
Singwe Bush Camp	0.400	0.507	10.600	-2.785	8.729
Toni's	0.408	0.607	7.325	-2.390	5.949

Van Wyk's	0.448	0.469	12.750	-3.420	10.247
Control	0.374	0.521	7.650	-1.000	7.545
Waterhole type					
Earth dam	0.302	0.621	11.292	-3.289	8.9257
Pan	0.404	0.595	9.683	-2.652	8.030
Reservoir	0.434	0.570	11.308	-3.273	9.039
Control	0.374	0.521	7.650	-1.000	7.545

No significant variation was found when considering habitat scores and waterhole types (x^2=0.96, df=3, *p*=0.81) (Figure 5.8).

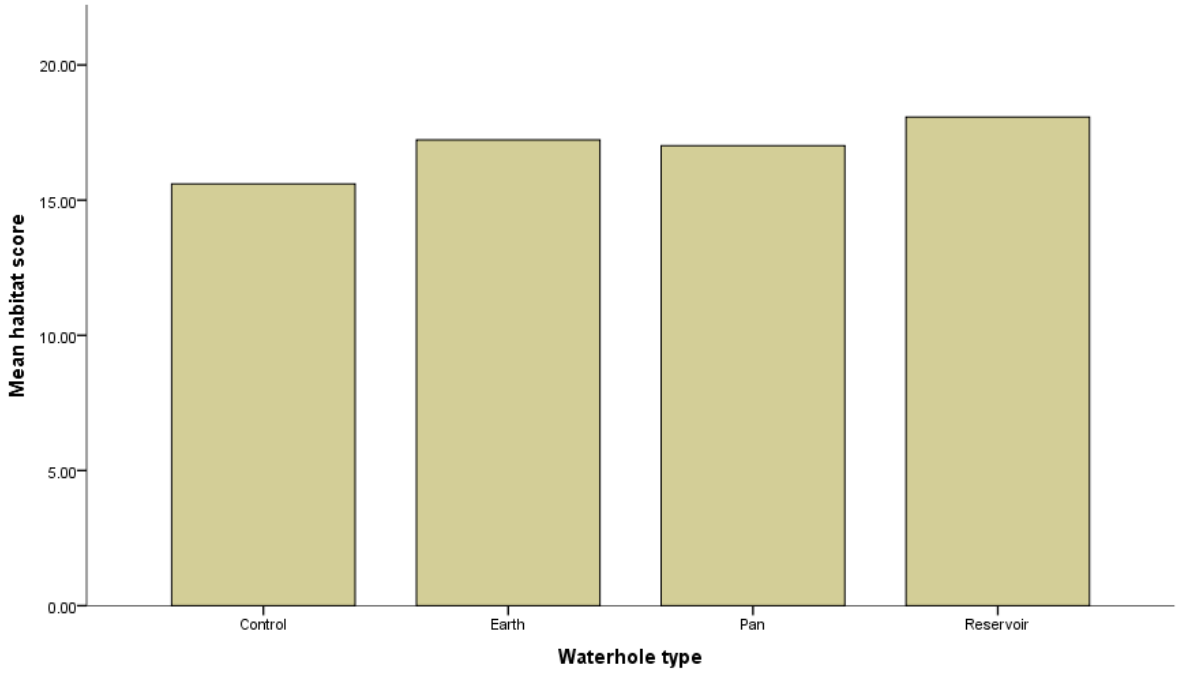


Figure 5.8: Mean habitat scores for the different waterhole types.

Habitat score comprised of a combination of data collected from both the woody and herbaceous layers. As with the separate analysis of these components, habitat score was not influenced by distance from the study waterholes (x^2=1.06, df=4, *p*=0.90). Habitat score was also not influenced by minimum distance from all water sources (r=-0.08, df=179, *p*=0.31).

No significant correlations were recorded for habitat scores and number of waterholes within a 1 km radius of the study waterholes (0.018, df=179, *p*=0.81) or for habitat scores and minimum distance from drainage lines (r-0.122, df=179, *p*=0.10).

5.4 Discussion

Various researchers suggest that vegetation decline around waterholes is a result of herbivore grazing and browsing pressure (Thrash *et. al.* 1995; Thrash 1998; Smit *et. al.* 2007), with high impact species such as elephants contributing noticeably (Sankaran *et. al.* 2008). In this study vegetation was assessed to determine the influence of herbivores on vegetation surrounding artificial waterholes and the impact that artificial waterholes have on habitat integrity.

A scoring method was developed to determine the habitat integrity of areas surrounding artificial waterholes in Olifants West Nature Reserve (OWNR) to quantify the extent to which waterholes affect the landscape. Distance of vegetation plots from waterholes was taken into consideration.

5.4.1 Herbaceous layer

Veld condition score was used to assess the condition of the herbaceous layer. Veld condition scores were highest at reservoirs, followed by pans and the control site. Earth dams had the lowest VCS. Variations in VCS are due to herbivores having preferences for specific waterhole types (Smit *et. al.* 2007), for example reservoirs have high sides that restrict access to common grazers such as zebra; however, two out of the three reservoirs had troughs that allowed all species access to water.

High densities of waterholes in areas result in lower VCS (Owen-Smith 1996; Thrash 2000). Both the highest mean veld condition score and the lowest waterhole density were observed for reservoirs, indicating that low waterhole densities are associated with higher

VCS. The area surrounding Ngala dam, an earth dam, had the lowest waterhole density and the second lowest VCS, suggesting that waterhole type is a more significant determinant of VCS. The control site was expected to have a comparatively high veld condition score due to a lack of disturbance and no utilisation from herbivores; however, it is well documented that while over-grazing is detrimental to grazing quality and biodiversity (Olff & Ritchie 1998; Arsenault & Owen-Smith 2002), a complete lack of grazing may have a similarly negative effect on grazing quality and biodiversity (Arsenault & Owen-Smith 2002). For example, in the Serengeti, wildebeest grazing was found to stimulate re-growth of leafy grass species and increase grass density (McNaughton 1976).

The relationship between distance of plots from study waterholes to VCS was not significant. This could be related to the high number of waterholes in the area and the potential overlap of transects from adjacent waterholes meaning that the distance from the study waterhole was not necessarily the minimum distance from water. Minimum distance to any other water source was taken into consideration and this was also not significantly related to VCS. In addition, waterhole density was not significantly related to VCS. A significantly higher VCS was found closer to drainage lines due to the dense vegetation associated with riparian zone moisture regimes (Balme *et. al.* 2007), resulting in an abundance of high scoring grass species, including *Panicum maximum*, which occurred mainly under trees (Smit & Rethman 1989).

5.4.2 Woody layer

Abundance of woody species is reported to decrease with increasing proximity to water (Chamaillé-Jammes *et. al.* 2009; Brit *et. al.* 2002) due to increased browsing pressure (Chamaillé-Jammes *et. al.* 2009) and the detrimental effect of trampling on seedling recruitment caused by increased herbivore traffic close to and around to water (Roques *et. al.* 2001).

Occurrence of woody species was more or less uniform across the study sites, with *Grewia* spp., *Combretum apiculatum* and *Commifera* spp. dominating. *Senegalia nigrescens* and *Dichrostachys cinerea* were also common.

Reservoirs had the highest average number of trees or shrubs per plot, followed by earth dams, pans and the control site with the lowest average number of trees per plot. The low number of trees at the control site is related to its location away from the influence of herbivores, who contribute towards bush encroachment (Eckhardt *et. al.* 2000).

Increased concentrations of wildlife associated with waterholes (Smit *et. al.* 2007) results in increased grazing and trampling pressure on the herbaceous layer, allowing young trees and shrubs to establish by reducing the competitiveness of the herbaceous layer (Roques *et. al.* 2001; Ward 2005). Further to this, elephants have been shown to increase numbers of trees (Kalwij *et. al.* 2010) and therefore high numbers of elephants utilising reservoirs could explain a high number of trees at this waterhole type.

5.4.3 Woody layer: height

The height of woody species varied significantly for the different waterhole types, suggesting that variation in herbivore utilisation between waterhole types impacts the height of woody species. The control site was associated with the greatest woody species height, followed by earth dams, then pans, then reservoirs. The greater height of woody species in the control site compared to the woody species surrounding the study waterholes suggests that the influence of herbivores may have contributed to a reduced woody species height where they were present. Kalwij *et. al.* (2010) determined that elephants caused a reduction in woody species height in Chobe, however, it is unlikely that this is the only species contributing to a lower woody species height around study waterholes, as the variation in woody species height was not consistent with the variation in numbers of elephant visits.

Distance from water and waterhole density were not significantly related to woody species height. This result is in accordance with Kalwij *et. al.* (2010) who determined that the introduction of artificial waterholes had not caused a reduction in woody species height, but rather this this was associated with a growing elephant population.

5.4.4 Woody layer: disturbance

The greatest level of disturbance was seen on *Senegalia nigrescens*, which were most prevalent at earth dams. Earth dams were also where the greatest level of disturbance was observed. The association between these results can likely be attributed to the browsers selecting *Senegalia nigrescens* due to their palatability (Du Toit *et. al.* 1990; Fornarra & Du Toit 2007). Additionally, disturbance may come from the movement patterns of larger herbivores, which knock branches off trees or bend branches. Disturbance to woody species was not attributed to the herbivore species investigated; however, certain disturbance patterns were related to particular feeding behaviour. For example, minor incidences of broken branches, where the ends of small branches are broken, may be attributed to browsing herbivores, and depending on the height of the disturbance, to specific species (Bergström 1992). Taller browsing species such as giraffe and kudu are associated with a higher browse line, while a lower browse line is associated with smaller browsers such as impala, steenbok and duiker (Dayton 1978). Although elephants are the largest herbivore species found in the study area, with a reputation for pushing over trees (Sankaran *et. al.* 2008), it is not realistic to attribute all 'pushed over' trees to elephants, since this disturbance category was observed at the control site, where there were no elephants. Trees that have been 'pushed over' could also be the result of strong wind (Cook & Goyen 2008), particularly if trees have previously been weakened by fire (Higgins *et. al.* 2000) or drought (Bond 2008). Elephants were; however, implicated in the mortality of *Grewia* spp. that were completely uprooted (Shannon *et. al.* 2006). *Grewia* spp. bushes were the most frequently observed plant species at the study waterholes and uprooting was attributed to 3.2% of *Grewia* spp. bushes recorded. Total tree fatalities were recorded at 3.7% for all individuals, suggesting that although disturbance was widely recorded, the negative impact on woody species may be limited.

The amount of disturbance recorded per tree was proportional to the tree's height. For example, in the case of *Senegalia nigrescens*, there was a significant relationship between height and disturbance. As their height increased, so did levels of disturbance. This could be as a result of previous damage, implying that larger trees have had more time to accumulate damage. Other frequently occurring species, with the exception of *Senegalia erubescens*,

Commifera spp. and *Dichrostachys cinerea*, showed the same pattern. In the case of *Grewia* spp., individuals between 1.5m and 3.0m, were recorded to have a mean disturbance level higher than for those between 3.0m and 4.5m. In the case of the *Dichrostachys cinerea*, the smallest height category <0.5m had the highest amount of disturbance. Similarly, *Senegalia erubescens* had a marginally higher amount of disturbance in this height class than for the 0.5m to 1.5m height class, with the greatest amount of disturbance recorded for the highest class. Numerous trees in the <0.5m height class indicate that they were previously in higher height classes, but have been broken and now occur in the <0.5m height class. *Commifera* spp. were observed in all height classes, but the greatest mean disturbance was found for trees between 0.5m and 1.5m. This height class also had the second highest percentage of dead trees, 1.38%. Monitoring woody species over the long term will provide information about whether small trees were specifically targeted or if they were recorded as small trees because they had previously been targeted and broken down to that height class.

When considering levels of disturbance for the different waterhole types, earth dams were associated with the highest amount of disturbance, followed by pans and reservoirs. The control site was significantly less disturbed than the study waterholes. This suggests that herbivores have a noticeable influence on woody species within the Olifants West Reserve.

5.4.5 Woody layer: species diversity

To provide accurate results, woody species diversity was calculated using the largest sample size possible. Data were grouped according to waterhole type and plot distance from the study waterholes (200m, 400m, 600m, 800m or 1000m). Mean species diversity was calculated for the different waterhole types. The control site represents an area of low disturbance given its position outside of herbivore influence. The lowest species diversity was recorded for the control site and can be attributed to the intermediate disturbance hypothesis, which suggests that increased diversity is observed in areas with intermediate levels of disturbance (Connell 1978). For this study, the highest disturbance was recorded at earth dams which also had the highest woody species diversity. This does not necessarily refute the intermediate disturbance hypothesis, as parameters for what defines intermediate disturbance were not investigated. The absence of herbivores from the control

site could lead to a reduction in woody species diversity as herbivore seed dispersal does not take place (Miller 1996).

A significant relationship between minimum distance from waterholes and species diversity was found at earth dams, indicating that diversity was highest nearest to water. Disturbance was also found to be highest closer to waterholes resulting in increased woody species diversity as disturbance and species diversity are subtly related (Connell 1978; Hobbs & Huenneke 1992; Mackey & Currie 2000).

Woody species diversity at earth dams increased closer to the water as a result of increased disturbances preventing the establishment of large tree species which would out-compete seedlings (Roques *et. al.* 2001). This is supported by the nature of earth dams, which are often associated with existing drainage lines that are moisture rich.

5.4.6 Habitat score

The final habitat score per plot was derived from a combination of veld condition score, disturbance score, community structure and species diversity. Higher scores were associated with increased VCS, community structure and species diversity, while lower scores were associated with high levels of disturbance. The greatest mean habitat score was observed for reservoirs, followed by earth dams and pans. The control site had the lowest mean habitat score.

The herbaceous layer competes with the woody layer for moisture and nutrients, resulting in a trade-off between grazing and browse quality (Walker *et. al.* 1981). Correlations between veld condition scores were carried out against community structure, disturbance and species diversity to determine if a trade-off exists between quality of grazing and quality of browse. A significant correlation was found between average disturbance per plot and VCS, with disturbance levels decreasing as VCS increases. This is likely as a result of fewer browsers occurring in areas with more grasses and subsequent higher VCS. As suggested by Walker *et. al*. (1981), decreased availability of browse results in less disturbance by browsers, which makes logical sense. Despite the assertion that the herbaceous layer

competes with the woody layer, it is important to note that studies show increased nutrient levels under savannah tree canopies (Ludwig *et. al.* 2003), as a result of the increased occurrence of the high quality grass *Panicum maximum* under savannah trees (Treydte *et. al.* 2011).

5.5 Conclusions

Results for this study do not consistently correspond with previous studies that suggest that habitat integrity increases with increasing distance from water as with the piosphere model (Thrash 2000). Variations in data recorded for this study may be attributed to the high density of artificial waterholes in the study area preventing the establishment of consistent herbivore movement and foraging patterns as reported in other studies that recommend a minimum 10 km distance between water sources (Smit *et. al.* 2007; Thrash *et. al.* 1995). Further to this, other studies do not find patterns of vegetation variation (Chamaillé-Jammes *et. al.* 2009). However, results for this study are largely attributed to an investigation into larger areas of non-homogenous vegetation, concluding that a piosphere model is only relevant for small scale investigations (Thrash 1998; Farmer 2010). Studies using the piosphere model are often on much smaller scales compared to this study.

The impact of artificial waterholes is affected by herbivore stocking rates (Thrash 2000). If herbivore densities are low, expected utilisation patterns do not emerge. The results for this study show higher habitat scores for the study site compared to a control site, suggesting that herbivore densities at the study site are not high enough to create a consistent piosphere effect.

Previous studies have identified a relationship between distance from water sources and variations in vegetation (Chamaillé-Jammes *et. al.* 2009; Smit *et. al.* 2007; Nangula & Oba 2004; Thrash 2000; Thrash 1998; Owen-Smith 1996). When all waterholes were considered together, relationships were found between minimum distances from waterholes and habitat scores at pans, and between diversity and disturbance at earth dams. Plot distance

from study waterholes was found to be significant variable when considering the habitat scores at earth dams but not when data from all waterholes was considered together. The theory that habitat integrity is lower closer to water sources was observed for this study, with disturbance caused by herbivores increasing closer to the study waterholes. However, in the case of habitat scores for pans, and habitat score and species diversity at earth dams, there was a decline in habitat integrity with increasing distance from water, suggesting that besides artificial waterholes, other confounding variables influence habitat integrity.

The impact of artificial waterholes is affected by herbivore stocking rates (Thrash 2000). When herbivore densities are low, expected disturbance patterns do not emerge. This was observed for the control site that had lower habitat scores compared to the study waterholes, indicating that herbivore densities need to be consistently high enough to create a piosphere effect.

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Chapter 6 : Assessing the influence of waterhole design on habitat integrity with reference to specific herbivores

6.1 Introduction

The impact of herbivores on vegetation varies depending on herbivore species and their population densities (Grange & Duncan 2006). According to Trollope *et. al.* (1998), large herbivores like elephants are responsible for declines in vegetation. The quality of vegetation surrounding artificial waterholes is influenced by the different herbivore species frequenting the waterholes most.

Grazers include species that:

- are roughage feeders able to efficiently digest fibrous grasses, valuing quantity over quality, such as waterbuck and buffalo (Seydack *et. al.* 2012a)
- select for high-nitrogen quality in shorter grasses, such as blue wildebeest and zebra (Seydack *et. al.* 2012b).
- are selective grazers that are more versatile than blue wildebeest and zebra in terms of preferred grass length, select grasses with a high carbon-nutrient quality, valuing quality over quantity, such as sable and roan antelope (Seydack *et. al.* 2012a).

Grange & Duncan (2006) found that wildebeest were abundant only on nutrient rich soils, in contrast with buffalo which were more abundant on low nutrient soils.

In the Kruger National Park there has been a trend towards increasing the population sizes of bulk feeders such as zebra, wildebeest and buffalo (Seydack *et. al.* 2012b). This could lead to overgrazing that could cause degradation of the vegetation leading to an increase of

lower quality grass species (Van Rooyen *et. al.* 1996). This could be to the detriment of selective grazers that rely on high value grass species. In addition to this, there may also be an adverse effect on woody species recruitment as non-selective, bulk feeders have a particularly high impact on woody plant species seedlings, consuming them whilst grazing (Midgely *et. al.* 2010). Research has however, also proved that woody species density increase due to overgrazing where the competition from the herbaceous layer is removed (Joubert *et. al.* 2008)

Notable browsing species include black rhino, giraffe and kudu (Mukinya 1977; Smit *et. al.* 2007). Browsers may feed on all parts of woody vegetation, including the leaves, twigs, roots, thorns, bark, flowers, seed-pods and fruits (Bergström 1992). Relative consumption of woody plant parts is browser species dependent, for example, the largest part of a giraffe's diet is composed of shoot-tips and leaves (Bergström 1992). Further to this, flower and fruit production is seasonal, so consumption of these items varies depending on the time of year. Similarly, roots may be targeted more in the dry season when alternative forms of nutrition are scarce (O'Connor *et. al.* 2007). During the dry season different species of woody plants are targeted, for example the evergreen species, *Euclea divinorum*, is targeted when other woody species have no leaves (Kerr *et. al.* 1970).

Browsing herbivores browse to varying degrees of impact on woody vegetation. Herbivory has the potential to change the overall shape or growth pattern of a tree due to the nature of branch re-growth; however, browsing by herbivores has a low impact on tree mortality beyond the seedling stage (Midgley *et. al.* 2010). Seedlings, in contrast, are highly susceptible to herbivory and trampling as they have a less developed re-sprouting ability (Midgley *et. al.* 2010). This is particularly relevant when considering recruitment in relation to woody species utilisation around waterholes given the increase in herbivore traffic around waterholes. The effect of trampling also compounds with increasing herbivore body size (Cumming & Cumming 2003).

Mixed feeders rely on both herbaceous vegetation and woody vegetation for their nutritional requirements. Some grazers are known to browse under certain conditions, for example buffalo during the dry season when grazing is limited (Venter & Watson 2008;

Codron *et. al.* 2006), and browsers graze, for example duiker graze during the wet season when grasses are most nutritious (Codron *et. al.* 2006). Herbivores classified as mixed feeders have a significant impact on woody species, for example, elephants are implicated in large tree mortality (Bergström 1992; Midgley *et. al.* 2010) and impala are reported to have a high impact on seedling mortality (Midgley *et. al.* 2010). Unlike many other herbivores, elephants are known to browse on most parts of woody plant species, including the fruit (Morris *et. al.* 2006), leaves, bark and roots (O'Connor *et. al.* 2007). Due to their size, elephants consume greater amounts of forage than other species, with bulls having greater requirements than cows and calves (O'Connor *et. al.* 2007). Certain methods of feeding by elephants have a considerable impact on woody species, for example bark stripping may kill a tree in the following ways:

1. directly by cutting of the flow of nutrients from the roots to the growing tips
2. indirectly through insect infestation on damaged parts
3. indirectly by increasing susceptibility to fire (Jacobs & Biggs 2002).

Elephants are also known to push trees over, exposing them to further browsing damage by smaller browsers (Midgley *et. al.* 2010). These destructive elephant feeding habits, with the addition of shrub uprooting, only make up a small portion of elephant feeding behaviour (Tchamba & Seme 1993), even in the case of forest elephants who are more reliant on browse than graze (Codron *et. al.* 2006).

This chapter aims to explain variations in habitat integrity in relation to waterhole utilisation by specific herbivores, to determine if particular species are having more of an impact on vegetation than others, and whether impacts vary for the different waterhole types.

6.2 Methodology

Data from chapters 4 and 5 are used in this chapter to investigate associations between herbivore utilisation of waterholes (Chapter 4) and habitat integrity of the areas surrounding waterholes (Chapter 5).

Herbivore utilisation data was collected from camera traps set up at study waterholes. From photographs recorded by the camera traps, the average number of individuals to visit each waterhole per day per species was determined. Visiting species were categorised according to foraging strategy, with buffalo and elephant also categorised according to herd type. Herbivore utilisation data from Nyala reservoir and trough, and Van Wyk's reservoir and trough were combined as the reservoir and troughs were associated with the same vegetation plots due to their close proximity to each other.

Habitat integrity was determined using data collected from vegetation plots setup around each of the study waterholes. Data was collected for the herbaceous layer to calculate veld condition score (VCS). The woody component of each plot was surveyed to determine mean woody species height, mean perceived disturbance to each woody species in the plots, and the diversity of woody species in the plots. All vegetation data were combined into a single habitat score.

6.2.1 The influence of herbivores on habitat integrity

Pearson correlation tests carried out in IBM SPSS Statistics 21 were used to determine the significance of associations between herbivore utilisation of waterholes and habitat integrity of the areas surrounding waterholes. Numbers of individuals of each herbivore species visiting the different waterholes daily, numbers of individuals from the different foraging categories visiting the waterholes daily, and numbers of daily visits by different herd types, were correlated with habitat score, veld condition score (VCS), mean height of woody species, mean amount of disturbance to woody species and diversity of woody species.

6.2.2 Assessing the influence of herbivores on habitat integrity for different waterhole types

To assess waterhole design, the influence of herbivores on vegetation surrounding artificial waterholes was investigated for the different waterhole types to determine whether certain waterhole types and associated patterns of herbivore utilisation have a greater influence on the landscape than others.

Pearson's correlation tests were carried out using herbivore utilisation data from different waterhole types and vegetation data collected for these waterholes. Mean number of individuals per day of each species visiting the different waterhole types, mean number of individuals per day from each foraging category visiting the different waterhole types, and mean numbers of different herd types per day visiting the different waterhole types were correlated with habitat score, VCS, mean height of woody plant species, mean amount of disturbance to woody species, and diversity of woody plant species.

6.3 Results

6.3.1 The influence of herbivores on habitat integrity

The results of Pearson's Correlation tests carried out to determine if there were any significant associations between numbers of each species visiting waterholes and habitat integrity are shown in Table 6.1.

Table 6.1: Results of correlation tests carried out between number of individuals per species of herbivore per day and various vegetation data parameters collected. Df=180.

Habitat integrity variables	Number of individuals per species of herbivore per day											
	Black rhino		Buffalo		Duiker		Elephant		Giraffe		Impala	
	Cor.	Sig.	Cor.	Sig.	Cor.	Sig.	Cor.	Sig.	Cor.	Sig.	Cor.	Sig.
Habitat Score	-0.051	0.495	-0.062	0.41	-0.036	0.631	0.021	0.78	-0.034	0.649	0.032	0.668
VCS	-0.284	0	0.265	0	0.264	0	0.047	0.531	0.283	0	0.103	0.962
Diversity	0.43	0.59	-0.094	0.212	-0.119	0.111	0.047	0.527	0.017	0.824	0.103	0.17
Height	0.163	0.029*	-0.112	0.133	-0.075	0.32	-0.04	0.592	-0.132	0.77	-0.011	0.879
Disturbance	0.163	0.029*	0.039	0.603	0.003	0.97	0.04	0.598	-0.03	0.689	0.018	0.813

Table 6.1 continued

Habitat integrity variables	Number of individuals per species of herbivore per day											
	Kudu		Warthog		Waterbuck		White rhino		Wildebeest		Zebra	
	Cor.	Sig.	Cor.	Sig.	Cor.	Sig.	Cor.	Sig.	Cor.	Sig.	Cor.	Sig.
Habitat Score	-0.076	0.309	-0.059	0.432	-0.028	0.709	-0.007	0.927	-0.07	0.349	-0.025	0.736
VCS	-0.18	0.016*	0.097	0.193	-0.31	0	0.302	0	0.131	0.08	0.188	0.012*
Diversity	0.027	0.716	0.077	0.306	0.063	0.4	-0.136	0.069	0.053	0.482	-0.034	0.646
Height	0.166	0.026*	-0.065	0.389	0.19	0.011*	-0.09	0.23	-0.092	0.218	-0.102	0.171
Disturbance	0.098	0.192	0.037	0.626	0.139	0.062	0.024	0.753	0.022	0.77	0.063	0.398

*Significant correlation

Significant relationships were found for VCS and numbers of kudu and zebra visiting waterholes, for height of woody species and numbers of black rhino, kudu and waterbuck visiting waterholes, and for disturbance and numbers of black rhino visiting waterholes. These results are presented in Figure 6.1 to show the nature of the relationships.

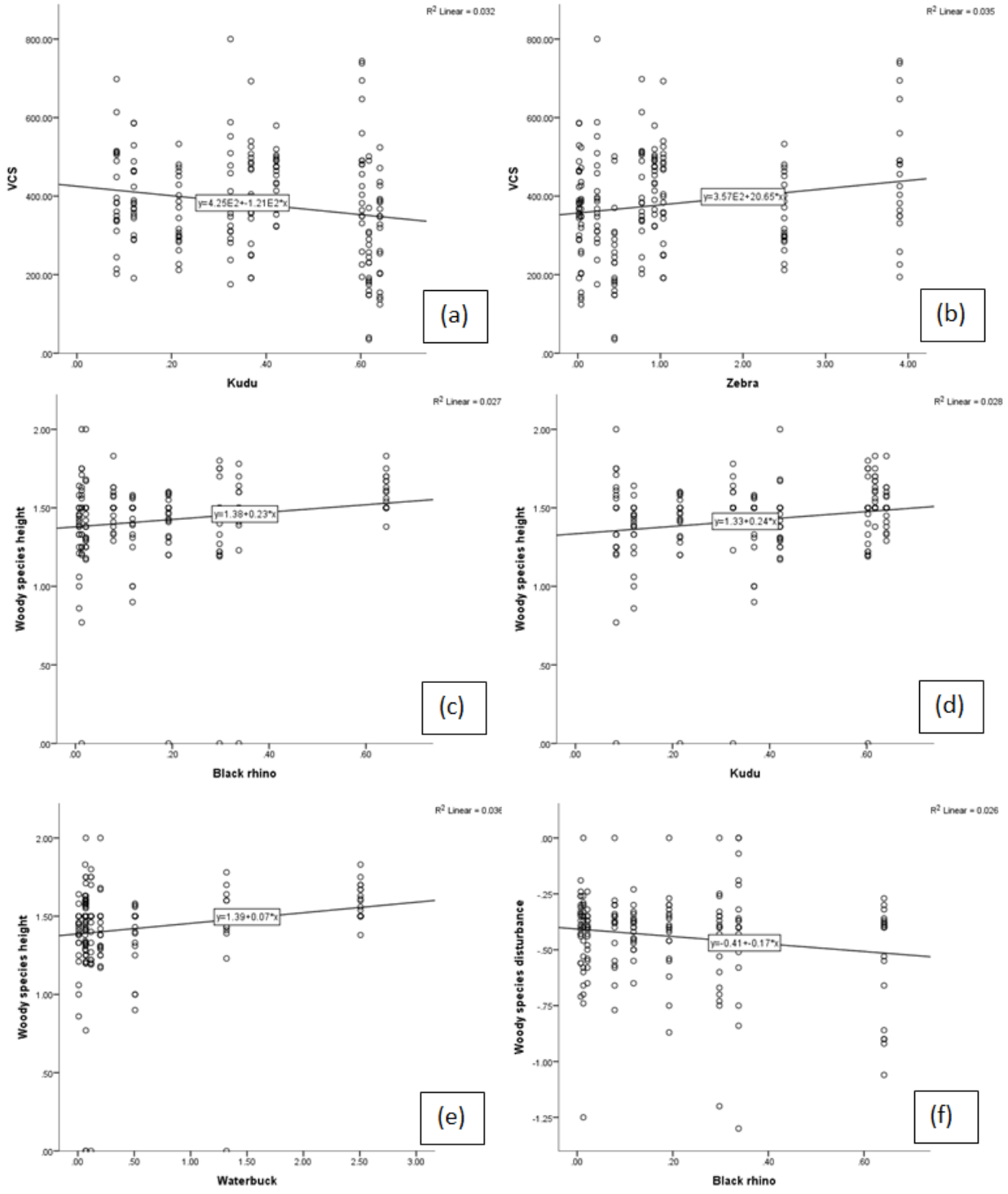


Figure 6.1: Nature of the relationships between: (a) VCS and numbers of kudu, (b) VCS and numbers of zebra, (c) woody species height and numbers of black rhino, (d) woody species height and numbers of kudu, (e) woody species height and numbers of waterbuck, and (f) disturbance to woody species and numbers of black rhino.

Positive associations were observed for VCS and numbers of zebra (Figure 6.1b), woody species height and numbers of black rhino (Figure 6.1c), woody species height and numbers of kudu (Figure 6.1d) and woody species height and numbers of waterbuck (Figure 6.1e). Negative associations were observed for VCS and numbers of kudu (Figure 6.1a), and woody species disturbance and numbers of black rhino (Figure 6.1f).

Table 6.2 shows results for correlation tests carried out to determine if there were any significant associations between visits to waterholes by herbivores with different foraging strategies (browsers, grazers and mixed feeders), and habitat integrity. Number of browsers had a significant negative association with VCS and a significant positive association with woody species height (Table 6.2). Veld condition score was significantly associated with grazers and mixed feeders.

Table 6.2: Results of correlation tests carried out for daily numbers of herbivores from the different foraging categories and vegetation data collected at the waterholes. Df=180.

Habitat integrity variables	**Browser**		**Grazer**		**Mixed feeder**	
	Cor.	**Sig.**	**Cor.**	**Sig.**	**Cor.**	**Sig.**
Habitat Score	-0.071	0.346	-0.013	-0.861	0.104	0.165
VCS	-0.213	0.004*	-0.225	0.002*	0.048	0.518
Diversity	0.023	0.760	0.005	0.943	0.088	0.239
Height	0.183	0.014*	0.082	0.273	-0.007	0.923
Disturbance	0.129	0.084	0.021	0.781	0.007	0.923

*Significant correlation

Significant results associated with Table 6.2 are presented graphically in Figure 6.2. A positive association was observed for woody species height and numbers of browsers.

Negative associations were observed for VCS and numbers of browsers and for VCS and numbers of grazers.

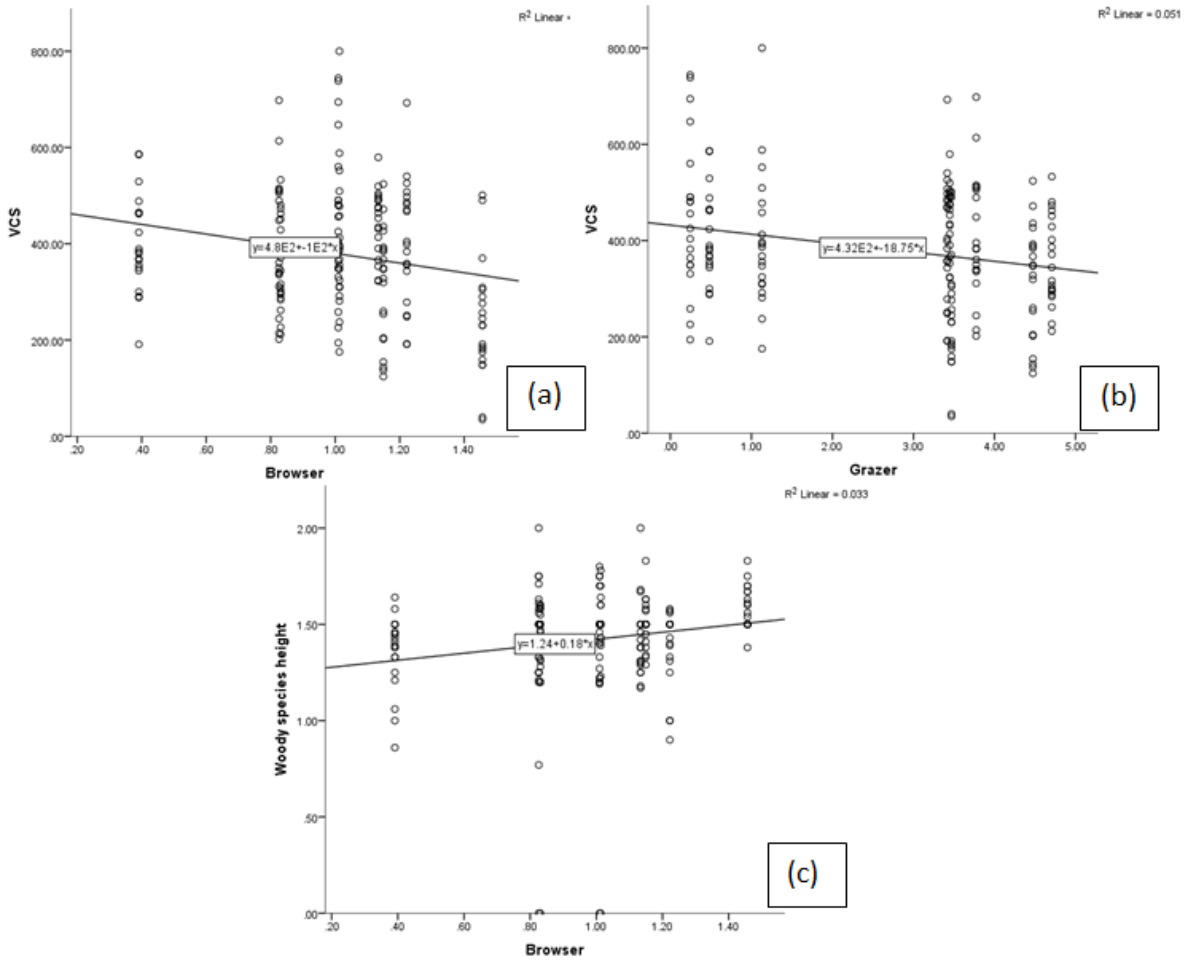


Figure 6.2: Nature of the relationships for: (a) VCS and numbers of browsers, (b) VCS and numbers of grazers, and (c) woody species height and numbers of browsers.

Table 6.3 shows the results of correlation tests carried out to determine the significance of associations between numbers of visits by the different herd types and habitat scores and its components. Veld condition score was positively correlated with number of visits by buffalo breeding herds and elephant breeding herds. Buffalo breeding herds were also negatively correlated with woody species diversity. Height of woody plant species was postively correlated with numbers of elephant bachelor herds.

Table 6.3: Results of correlation tests carried out between number of visits per herd type per day and vegetation data at each waterhole. Df=180.

Habitat integrity variables	Buffalo					
	Bachelor		Breeding		Lone male	
	Cor.	Sig.	Cor.	Sig.	Cor.	Sig.
Habitat Score	-0.020	0.790	0.000	1.000	-0.054	0.472
VCS	0.114	0.126	0.185	0.013*	-0.069	0.355
Diversity	-0.123	0.100	-0.178	0.017*	-0.085	0.254
Height	0.009	0.906	-0.020	0.792	0.124	0.098
Disturbance	-0.006	0.937	-0.038	0.614	0.087	0.245
Habitat integrity variables	**Elephant**					
	Bachelor		**Breeding**		**Lone male**	
	Cor.	**Sig.**	**Cor.**	**Cor.**	**Sig.**	**Cor.**
Habitat Score	-0.068	0.367	0.018	0.809	0.005	0.944
VCS	-0.331	0	0.193	0.01*	0.001	0.985
Diversity	0.024	0.747	-0.044	0.556	0.041	0.586
Height	0.202	0.006*	-0.046	0.542	0.019	0.805
Disturbance	0.073	0.332	0.047	0.527	0.065	0.387

*Significant correlations

Positive correlations were observed for VCS and number of visits by buffalo breeding herds (Figure 6.3a), for woody species height and number of visits by elephant bachelor herds (Figure 6.3c) and for VCS and number of visits by elephant breeding herds (Figure 6.3d). A negative correlation was observed for woody species diversity and number of visits by buffalo breeding herds (Figure 6.3b).

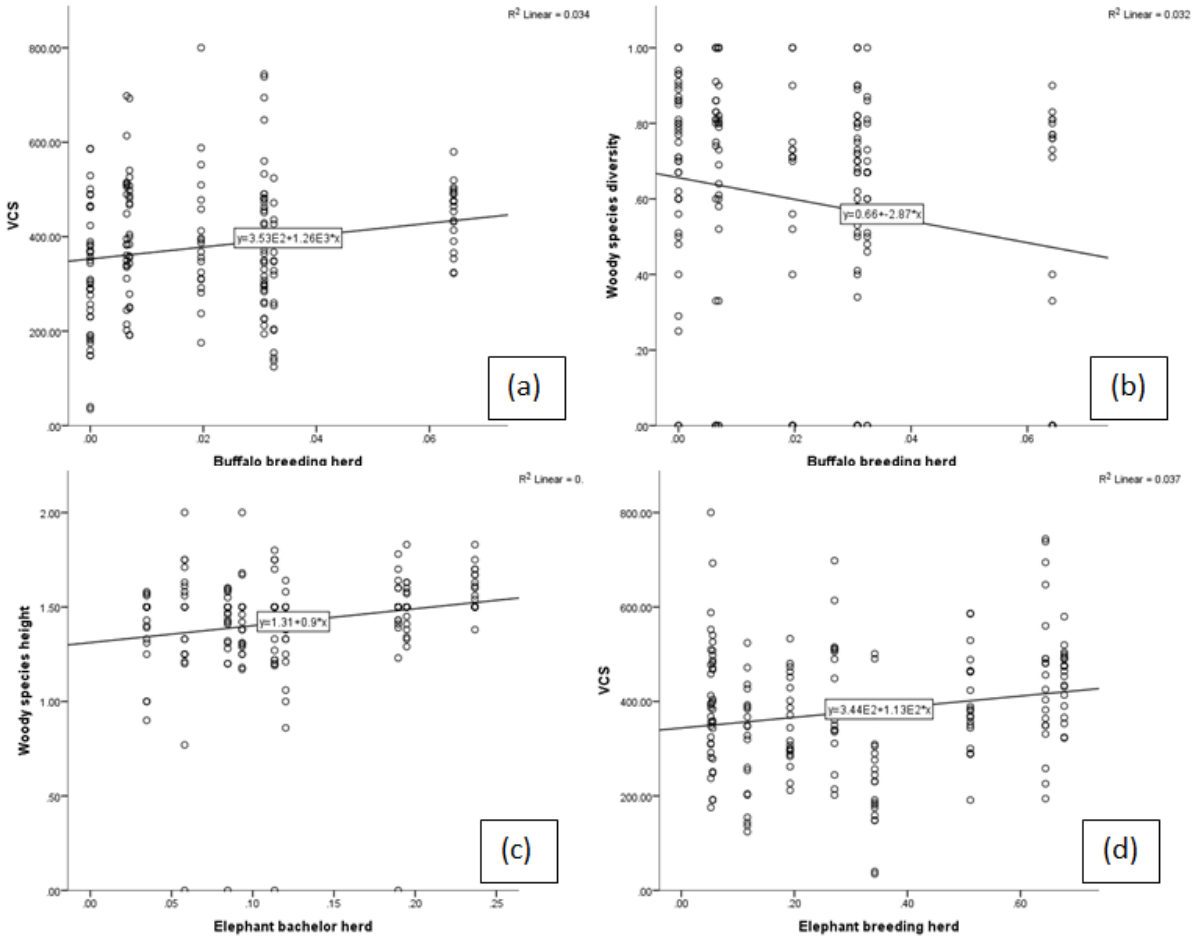


Figure 6.3: Nature of the relationships for: (a) VCS and number of visits by buffalo breeding herds, (b) woody species diversity and number of visits by buffalo breeding herds, (c) woody species height and number of visits by elephant bachelor herds, and (d) VCS and number of visits by elephant breeding herds.

6.3.2 The influence of herbivores on habitat integrity for the different waterhole types

A series of correlation tests were carried out to determine if the associations between herbivore utilisation of the different waterhole types and habitat integrity varied by waterhole type.

Table 6.4 shows the results of correlation tests between the number of individuals of each species visiting the different waterhole types and the variables associated with habitat integrity. Significant results were associated with earth dams, but not other waterhole types. At earth dams the only herbivore species not correlated with VCS was warthog. Significant positive correlations were found for woody species height and numbers of impala, kudu and waterbuck. Significant negative correlations were found for woody species height and numbers of buffalo, duiker, giraffe, white rhino, wildebeest and zebra. Significant positive correlations were also found for disturbance and numbers of duiker. Significant negative correlations were found for disturbance and numbers of black rhino, elephant, impala and waterbuck.

Table 6.4: Correlation tests for numbers of individuals of different herbivore species visiting the different waterhole types and habitat integrity variables. Df=60.

Waterhole type	**Habitat integrity variables**	**Independent Variables**											
		Black rhino		**Buffalo**		**Duiker**		**Elephant**		**Giraffe**		**Impala**	
		Cor.	**Sig.**	**Cor.**	**Sig.**	**Cor.**	**Sig.**	**Cor.**	**Sig.**	**Cor.**	**Sig.**	**Cor.**	**Sig.**
Earth dam	**Habitat Score**	-0.002	0.987	0.128	0.330	0.055	0.674	0.023	0.859	0.118	0.369	-0.029	0.824

	VCS	-0.339	0.008*	0.389	0.002*	0.394	0.002*	-0.300	0.020*	-0.398	0.002*	-0.372	0.003*
	Diversity	0.163	0.212	-0.196	0.134	-0.193	0.139	0.143	0.277	-0.199	0.127	-0.181	0.167
	Height	0.245	0.059	-0.374	0.003*	-0.324	0.012*	0.198	0.129	-0.373	0.003*	0.289	0.025*
	Disturbance	-0.278	0.031*	0.191	0.144	0.269	0.038*	-0.272	0.036*	0.208	0.110	-0.277	0.032*
Pan	**Habitat Score**	0.063	0.635	-0.185	0.157	-0.179	0.171	-0.242	0.063	0.042	0.749	0.213	0.102
	VCS	-0.027	0.835	0.024	0.854	0.025	0.851	0.008	0.952	0.024	0.858	0.004	0.979
	Diversity	-0.146	0.265	0.046	0.726	0.054	0.684	-0.101	0.444	0.187	0.153	0.160	0.223
	Height	0.069	0.602	-0.045	0.734	-0.047	0.722	0.008	0.953	-0.071	0.590	-0.036	0.784
	Disturbance	0.073	0.579	-0.096	0.465	-0.096	0.467	-0.075	0.567	-0.039	0.765	0.044	0.736
Reservoir	**Habitat Score**	-0.213	0.102	-0.207	0.112	-0.033	0.803	0.047	0.721	-0.223	0.087	-0.223	0.087
	VCS	0.125	0.341	0.198	0.129	0.140	0.286	-0.149	0.255	0.170	0.195	0.148	0.260
	Diversity	0.039	0.767	-0.117	0.371	-0.239	0.066	0.239	0.066	-0.038	0.776	0.003	0.980
	Height	-0.021	0.876	0.048	0.714	0.104	0.427	-0.104	0.429	0.013	0.922	-0.005	0.970
	Disturbance	-0.210	0.108	-0.229	0.078	-0.072	0.587	0.086	0.514	-0.232	0.074	-0.232	0.074

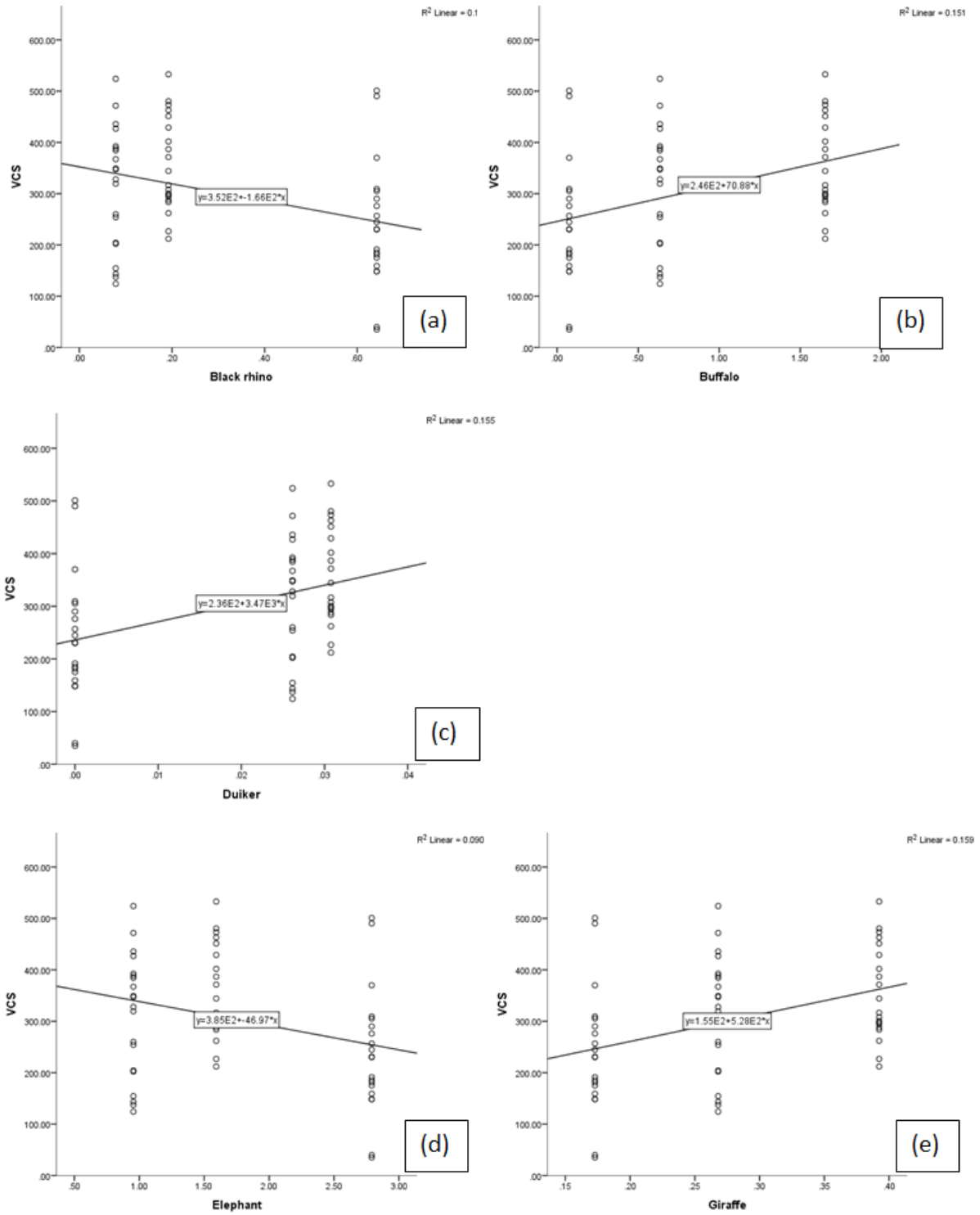
Table 6.4 continued

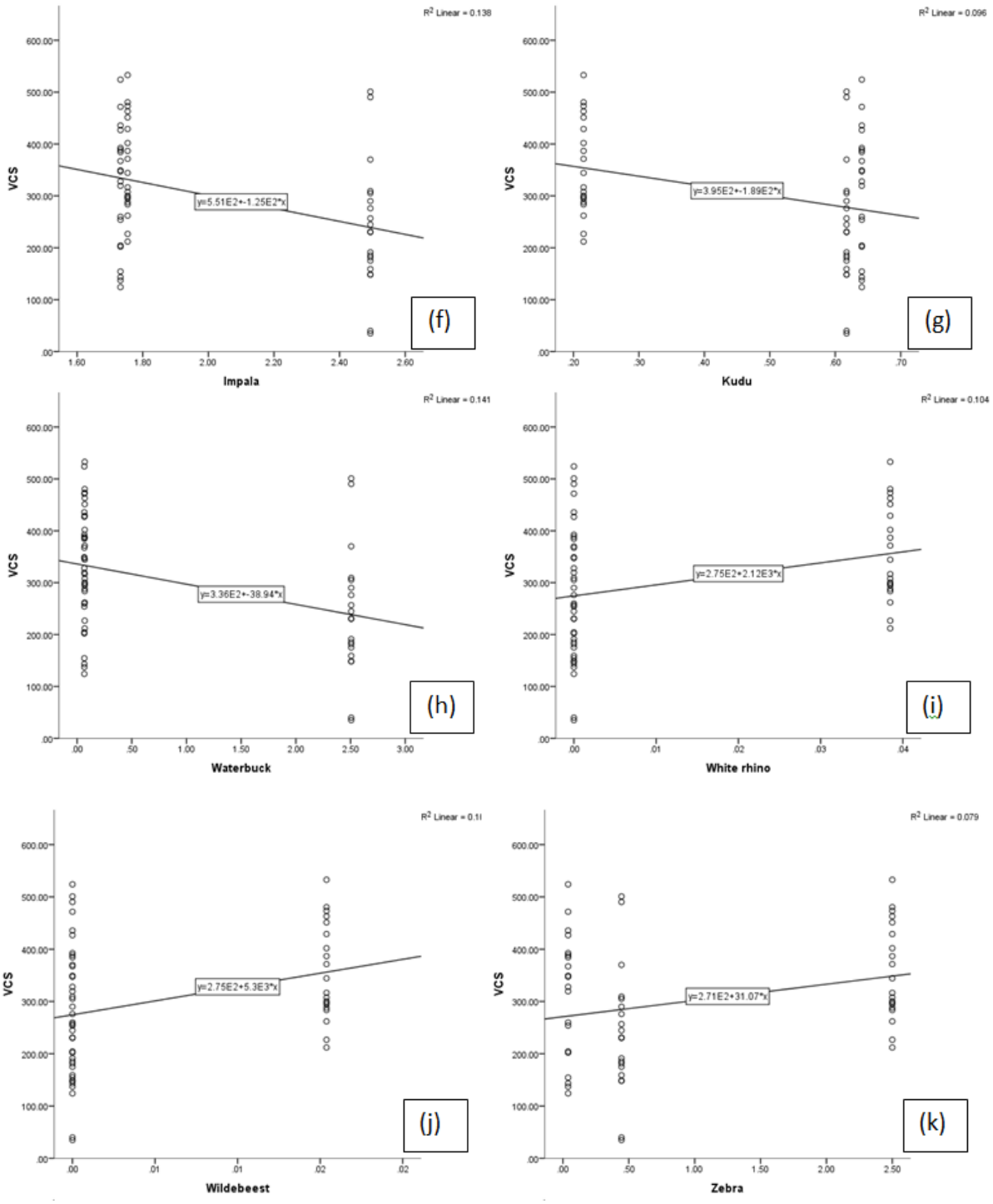
	Habitat integrity variables	**Independent Variables**											
		Kudu		**Warthog**		**Waterbuck**		**White rhino**		**Wildebeest**		**Zebra**	
		Cor.	**Sig.**	**Cor.**	**Sig.**	**Cor.**	**Sig.**	**Cor.**	**Sig.**	**Cor.**	**Sig.**	**Cor.**	**Sig.**

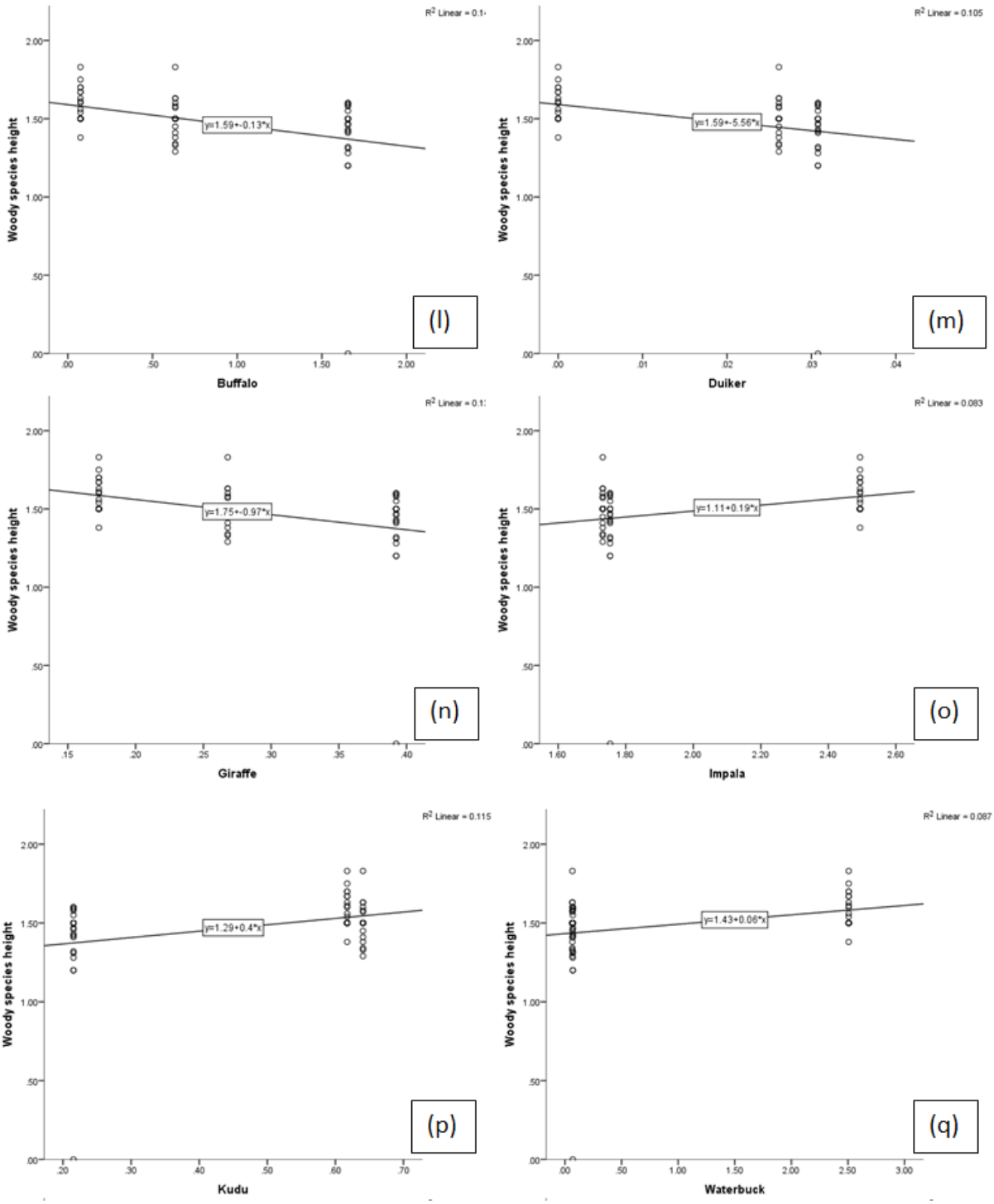
Earth dam	**Habitat Score**	-0.158	0.228	0.148	0.261	-0.033	0.801	0.156	0.235	0.156	0.235	0.162	0.218
	VCS	-0.310	0.016*	0.061	0.646	0.376	0.003*	0.323	0.012*	0.323	0.012*	0.281	0.030*
	Diversity	0.160	0.222	-0.039	0.767	0.183	0.162	-0.166	0.206	-0.166	0.206	-0.146	0.266
	Height	0.339	0.008*	-0.152	0.246	0.294	0.022*	-0.346	0.007*	-0.346	0.007*	-0.321	0.012*
	Disturbance	-0.095	0.468	-0.100	0.445	-0.277	0.032*	0.108	0.411	0.108	0.411	0.067	0.609
Pan	**Habitat Score**	0.219	0.093	0.004	0.977	0.069	0.599	-0.181	0.167	-0.104	0.428	0.091	0.487
	VCS	-0.020	0.879	0.026	0.846	-0.028	0.834	0.025	0.852	0.028	0.834	0.020	0.879
	Diversity	0.004	0.979	0.176	0.179	-0.142	0.278	0.051	0.696	0.120	0.360	0.194	0.137
	Height	0.029	0.826	-0.072	0.586	0.068	0.605	-0.046	0.726	-0.064	0.628	-0.067	0.610
	Disturbance	0.096	0.467	-0.053	0.688	0.075	0.570	-0.096	0.466	-0.083	0.527	-0.020	0.879
Reservoir	**Habitat Score**	-0.212	0.105	-0.223	0.087	-0.091	0.488	-0.103	0.434	-0.177	0.177	-0.222	0.089
	VCS	0.196	0.134	0.162	0.215	0.175	0.182	0.181	0.167	0.061	0.643	0.153	0.245
	Diversity	-0.106	0.419	-0.023	0.860	-0.230	0.077	-0.225	0.083	0.119	0.365	-0.005	0.970
	Height	0.043	0.743	0.007	0.960	0.099	0.450	0.097	0.460	-0.055	0.676	-0.001	0.992
	Disturbance	-0.232	0.075	-0.230	0.077	-0.129	0.325	-0.140	0.284	-0.160	0.222	-0.225	0.083

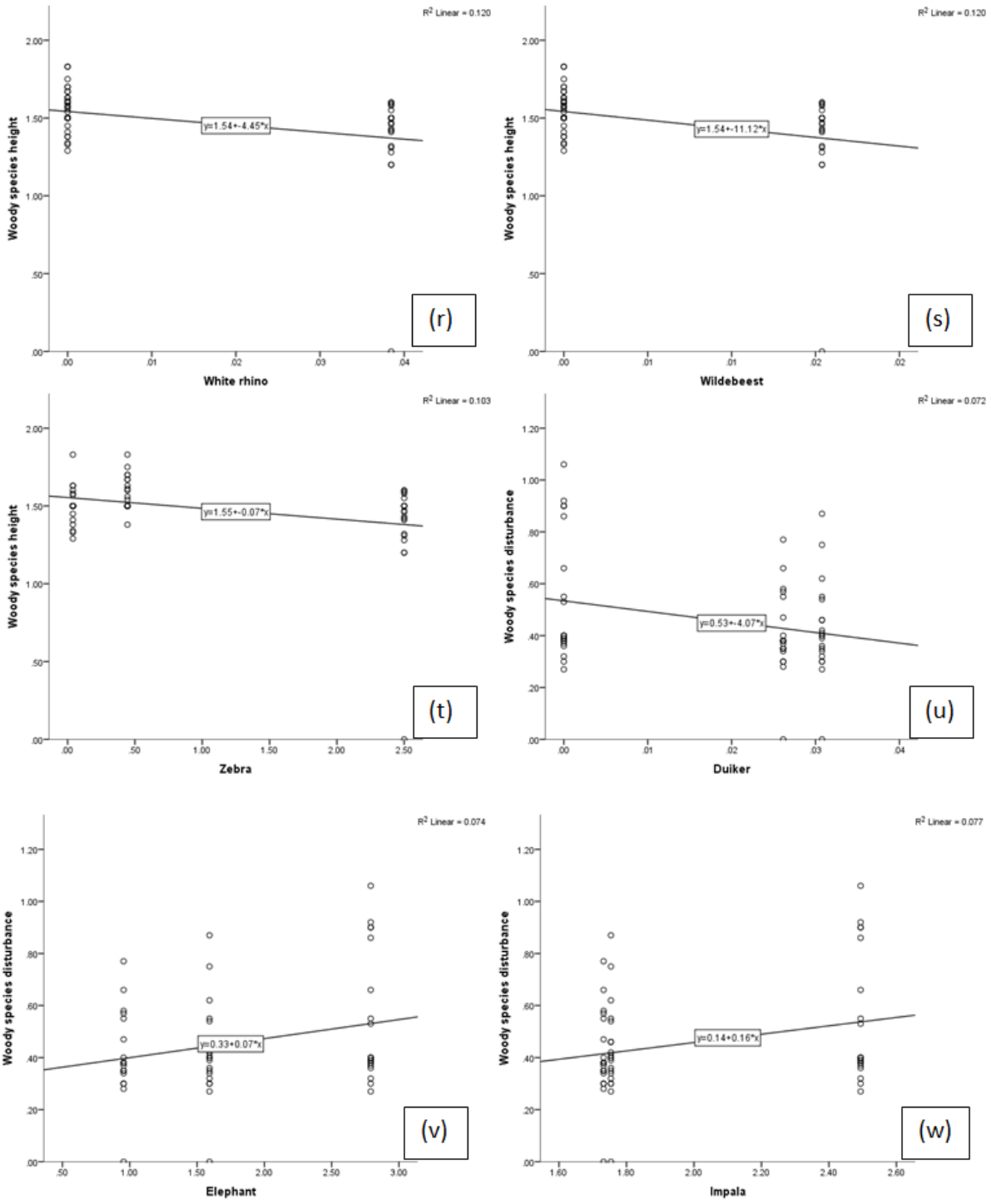
*Significant correlations

Significant correlations found between numbers of herbivore species visiting the different waterhole types and habitat integrity variables are graphically depicted in Figure 6.4.




R² Linear = 0.138
VCS
y=5.51E2+-1.25E2*x
(f)
Impala
R² Linear = 0.096
VCS
y=3.95E2+-1.89E2*x
(g)
Kudu
R² Linear = 0.141
VCS
y=3.36E2+-38.94*x
(h)
Waterbuck
R² Linear = 0.104
VCS
y=2.75E2+2.12E3*x
(i)
White rhino
R² Linear = 0.1
VCS
y=2.75E2+5.3E3*x
(j)
Wildebeest
R² Linear = 0.079
VCS
y=2.71E2+31.07*x
(k)
Zebra


Woody species height
Buffalo
y=1.59+-0.13*x
(l)
Duiker
y=1.59+-5.56*x
(m)
Giraffe
y=1.75+-0.97*x
(n)
Impala
y=1.11+0.19*x
(o)
Kudu
y=1.29+0.4*x
(p)
Waterbuck
y=1.43+0.06*x
(q)


R² Linear = 0.120
y=1.54+-4.45*x
Woody species height
White rhino
(r)
R² Linear = 0.120
y=1.54+-11.12*x
Woody species height
Wildebeest
(s)
R² Linear = 0.103
y=1.55+-0.07*x
Woody species height
Zebra
(t)
R² Linear = 0.072
y=0.53+-4.07*x
Woody species disturbance
Duiker
(u)
R² Linear = 0.074
y=0.33+0.07*x
Woody species disturbance
Elephant
(v)
R² Linear = 0.077
y=0.14+0.16*x
Woody species disturbance
Impala
(w)

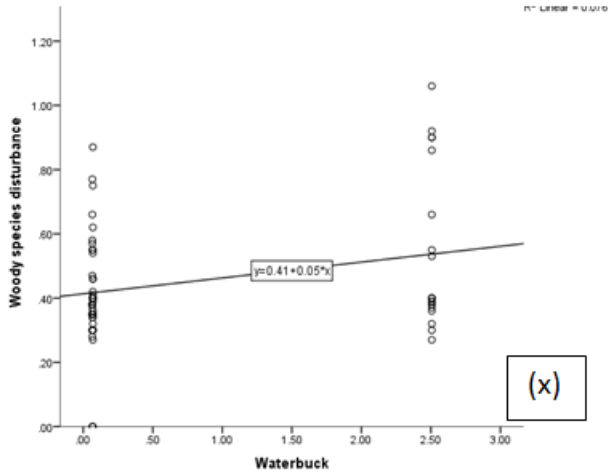


Figure 6.4: Nature of the relationships between: (a) VCS and numbers of black rhino to visit earth dams, (b) VCS and numbers of buffalo to visit earth dams, (c) VCS and numbers of duiker to visit earth dams, (d) VCS and numbers of elephant to visit earth dams, (e) VCS and numbers of giraffe to visit earth dams, (f) VCS and numbers of impala to visit earth dams, (g) VCS and numbers of kudu to visit earth dams, (h) VCS and numbers of waterbuck to visit earth dams, (i) VCS and numbers of white rhino to visit earth dams, (j) VCS and numbers of wildebeest to visit earth dams, (k) VCS and numbers of zebra to visit earth dams, (l) woody species height and numbers of buffalo to visit earth dams, (m) woody species height and numbers of duiker to visit earth dams, (n) woody species height and numbers of giraffe to visit earth dams, (o) woody species height and numbers of impala to visit earth dams, (p) woody species height and numbers of kudu to visit earth dams, (q) woody species height and numbers of waterbuck to visit earth dams, (r) woody species height and numbers of white rhino to visit earth dams, (s) woody species height and numbers of wildebeest to visit earth dams (t) woody species height and numbers of zebra to visit earth dams, (u) disturbance to woody species and numbers of duiker to visit earth dams, (v) disturbance to woody species and numbers of elephant to visit earth dams, (w) disturbance to woody species and numbers of impala to visit earth dams, and (x) disturbance to woody species and numbers of waterbuck to visit earth dams.

Table 6.5 shows the results of correlation tests carried out for the different waterhole types for habitat integrity variables and numbers of individuals from the different foraging categories visiting the waterholes. Significant correlations were found for earth dams for VCS and numbers of herbivores from all foraging categories, for woody plant species height

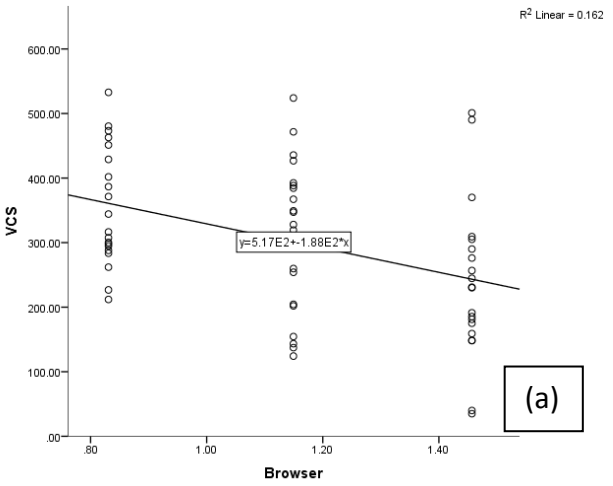
and numbers of individuals from all foraging categories, and between disturbance and grazers and mixed feeders.

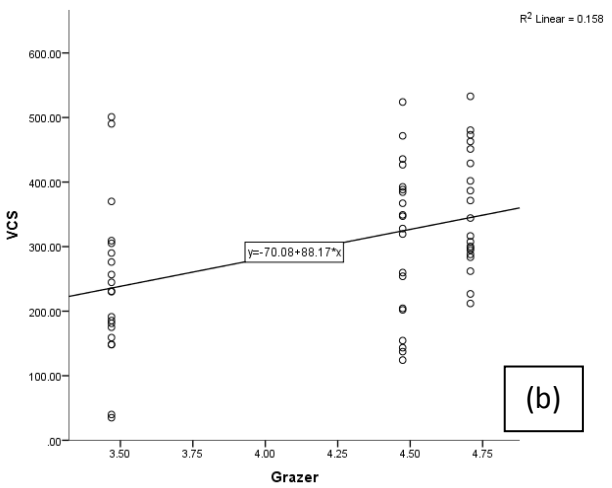
Table 6.5: Results of correlation tests carried out for the different waterhole types for habitat score, VCS, woody species diversity, woody species height, disturbance to woody species and numbers of browsers, grazers and mixed feeders to visit waterholes. Df=60.

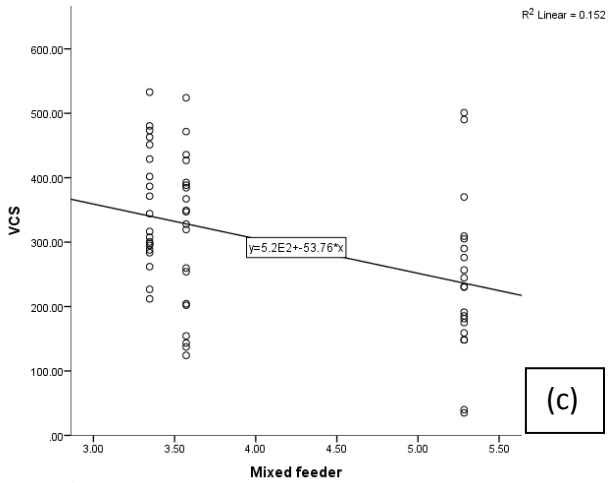
Waterhole type	Habitat integrity variables	Browser		Grazer		Mixed feeder	
		Cor.	Sig.	Cor.	Sig.	Cor.	Sig.
Earth dam	**Habitat Score**	-0.110	0.401	0.061	0.641	-0.050	0.703
	VCS	-0.403	0.001*	0.398	0.002*	-0.390	0.002*
	Diversity	0.201	0.123	-0.195	0.135	0.191	0.143
	Height	0.371	0.004*	-0.331	0.010*	0.318	0.013*
	Disturbance	-0.220	0.091	0.266	0.040*	-0.271	0.036*
Pan	**Habitat Score**	0.242	0.062	-0.015	0.908	0.197	0.132
	VCS	-0.011	0.935	0.026	0.842	0.007	0.958
	Diversity	0.082	0.536	0.169	0.198	0.172	0.188
	Height	0.000	0.999	-0.071	0.588	-0.044	0.741
	Disturbance	0.082	0.535	-0.059	0.654	0.033	0.801
Reservoir	**Habitat Score**	-0.146	0.267	0.054	0.679	0.105	0.426
	VCS	0.197	0.131	0.072	0.584	0.025	0.853
	Diversity	-0.201	0.124	-0.222	0.088	-0.194	0.137
	Height	0.086	0.514	0.098	0.455	0.087	0.509
	Disturbance	-0.180	0.169	0.020	0.881	0.075	0.569

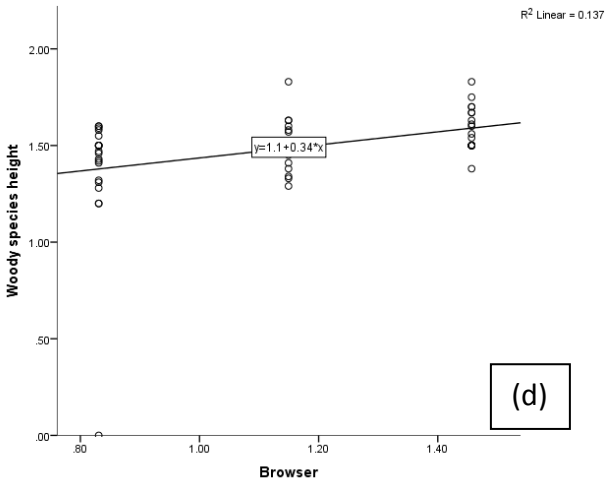
*Significant correlation

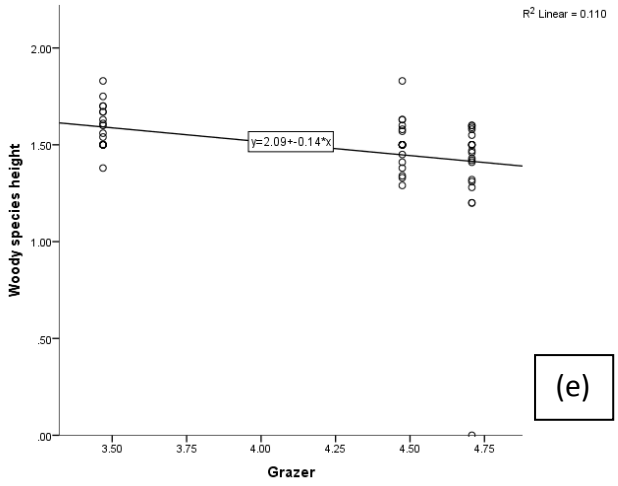
Positive correlations were observed between VCS and grazers, woody species height and browsers and woody species height and grazers. Negative correlations were observed between VCS and browsers, VCS and grazers, woody species height and grazers, woody species disturbance and grazers and woody species disturbance and mixed feeders. These results are shown graphically in Figure 6.5.

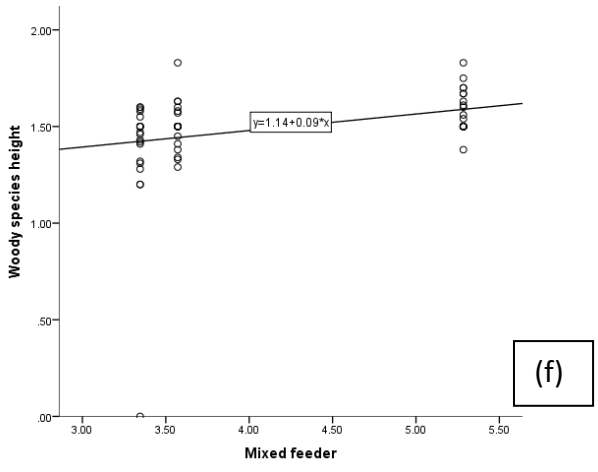

R² Linear = 0.162
VCS
y=5.17E2+-1.88E2*x
Browser
(a)


R² Linear = 0.158
VCS
y=-70.08+88.17*x
Grazer
(b)


R² Linear = 0.152
VCS
y=5.2E2+-53.76*x
Mixed feeder
(c)


R² Linear = 0.137
Woody species height
y=1.1+0.34*x
Browser
(d)


R² Linear = 0.110
Woody species height
y=2.09+-0.14*x
Grazer
(e)


Woody species height
y=1.14+0.09*x
Mixed feeder
(f)

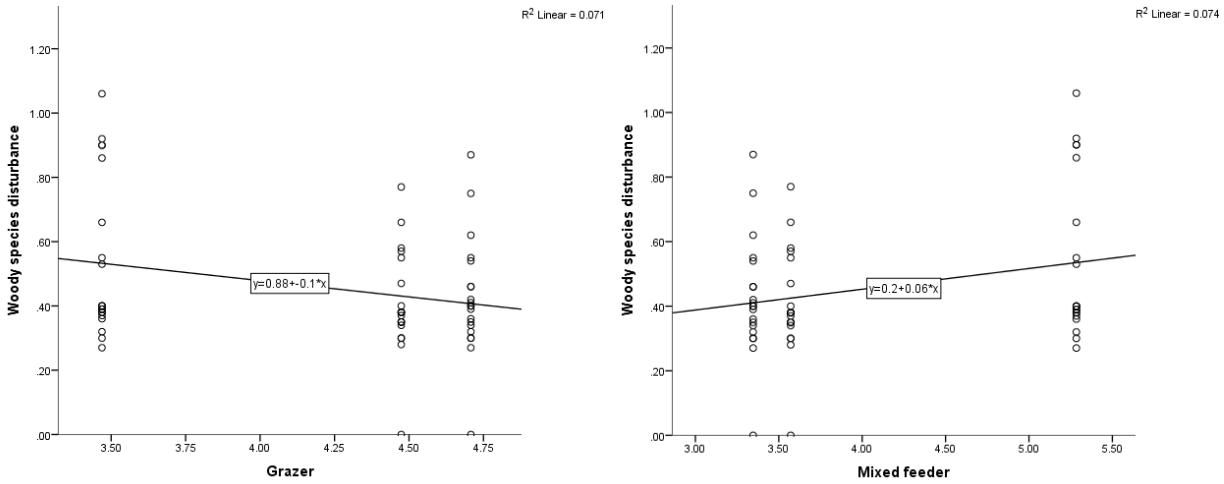


Figure 6.5: Nature of the relationships between (a) VCS and numbers of browsers to visit earth dams, (b) VCS and numbers of grazers to visit earth dams, (c) VCS and numbers of mixed feeders to visit earth dams, (d) woody species height and numbers of browsers to visit earth dams, (e) woody species height and numbers of grazers to visit earth dams, (f) woody species height and numbers of mixed feeders to visit earth dams, (g) woody species disturbance and numbers of grazers to visit earth dams, (h) woody species disturbance and numbers of mixed feeders to visit earth dams.

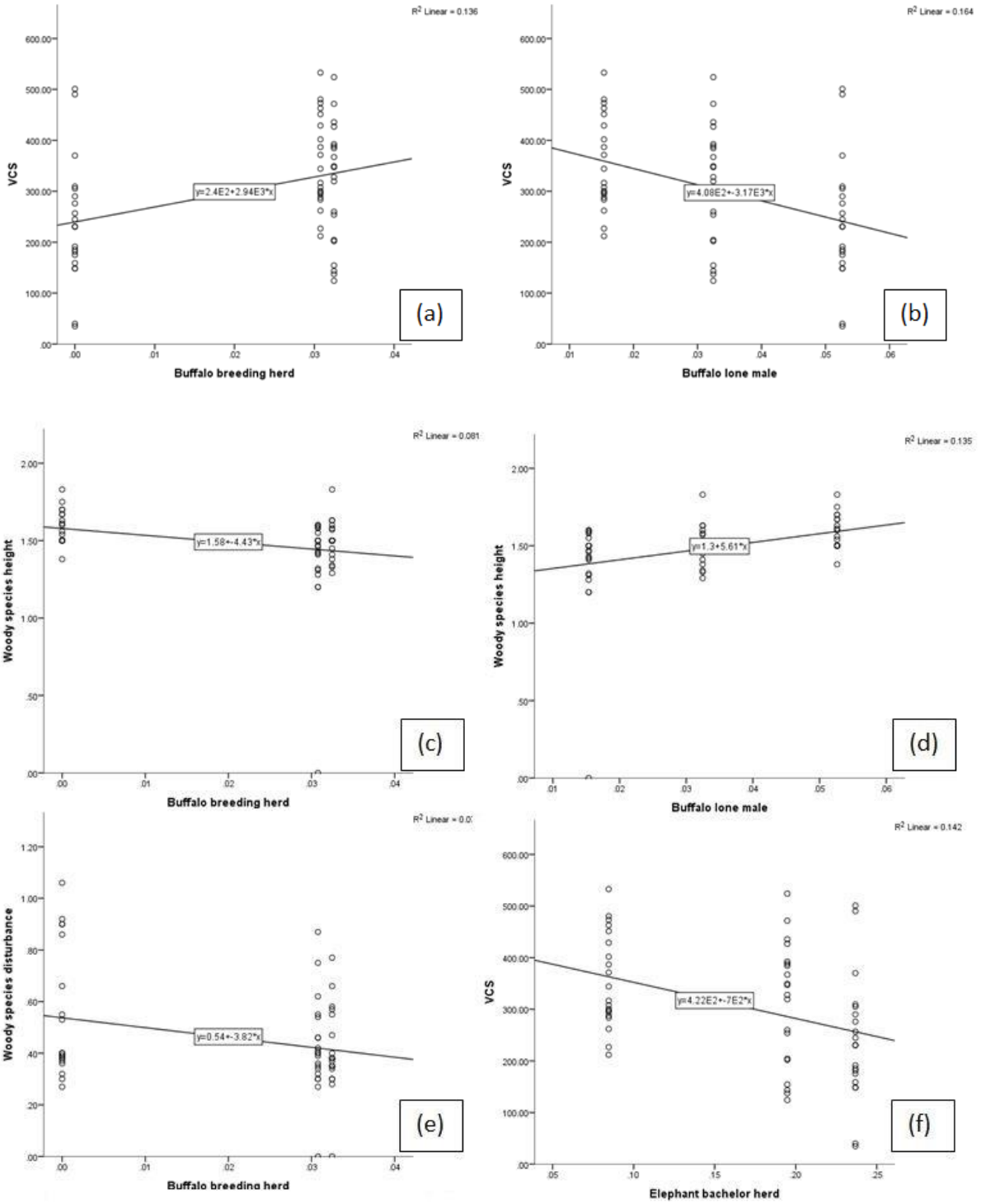
Table 6.6 and Figure 6.6 show the relationships between the different herd types of buffalo and elephant, and habitat integrity variables: habitat score, VCS, woody species diversity, woody species height and disturbance.

Table 6.6: Results of correlations carried out between habitat integrity variables and the numbers of each herd type per species to visit the different waterhole types. Df=60.

Waterhole type	**Habitat integrity variables**	**Buffalo**					
		Bachelor		**Breeding**		**Lone male**	
		Cor.	**Sig.**	**Cor.**	**Sig.**	**Cor.**	**Sig.**
Earth dam	**Habitat Score**	-0.103	0.435	0.026	0.844	-0.103	0.433
	VCS	0.118	0.369	0.368	0.004*	-0.406	0.001*
	Diversity	-0.050	0.705	-0.179	0.171	0.202	0.122

	Height	-0.009	0.944	-0.284	0.028*	0.367	0.004*
	Disturbance	0.202	0.121	-0.278	0.032*	-0.230	0.077
Pan	**Habitat Score**	-0.224	0.085	-0.007	0.957	-0.242	0.062
	VCS	0.019	0.885	-0.025	0.847	0.011	0.931
	Diversity	-0.013	0.919	-0.177	0.176	-0.077	0.558
	Height	-0.026	0.846	0.072	0.586	-0.002	0.988
	Disturbance	-0.095	0.471	0.052	0.694	-0.083	0.529
Reservoir	**Habitat Score**	0.052	0.691	-0.070	0.595	0.018	0.894
	VCS	0.074	0.574	0.163	0.213	0.103	0.434
	Diversity	-0.223	0.087	-0.235	0.070	-0.234	0.072
	Height	0.099	0.454	0.102	0.437	0.103	0.434
	Disturbance	0.018	0.894	-0.109	0.409	-0.020	0.882

	Habitat integrity variables	**Elephant**					
		Bachelor		**Breeding**		**Lone male**	
		Cor.	**Sig.**	**Cor.**	**Sig.**	**Cor.**	**Sig.**
Earth dam	**Habitat Score**	-0.136	0.300	0.021	0.873	-0.062	0.638
	VCS	-0.377	0.003*	-0.304	0.018*	-0.398	0.002*
	Diversity	0.191	0.145	0.145	0.270	0.196	0.134
	Height	0.371	0.003*	0.203	0.120	0.332	0.010*
	Disturbance	-0.173	0.187	-0.273	0.035*	-0.266	0.040*
Pan	**Habitat Score**	-0.049	0.712	-0.200	0.125	-0.214	0.100
	VCS	-0.023	0.860	0.023	0.863	-0.003	0.981
	Diversity	-0.188	0.150	0.027	0.840	-0.158	0.227
	Height	0.071	0.592	-0.039	0.769	0.035	0.789
	Disturbance	0.037	0.779	-0.097	0.462	-0.045	0.730
Reservoir	**Habitat Score**	0.015	0.909	-0.140	0.287	-0.059	0.652
	VCS	-0.128	0.331	0.196	0.134	-0.068	0.607
	Diversity	0.239	0.066	-0.205	0.116	0.220	0.092
	Height	-0.105	0.427	0.088	0.505	-0.097	0.459
	Disturbance	0.054	0.685	-0.175	0.182	-0.025	0.849


R² Linear = 0.136
VCS
y=2.4E2+2.94E3*x
Buffalo breeding herd
(a)
R² Linear = 0.164
VCS
y=4.08E2+-3.17E3*x
Buffalo lone male
(b)
R² Linear = 0.081
Woody species height
y=1.58+-4.43*x
Buffalo breeding herd
(c)
R² Linear = 0.135
Woody species height
y=1.3+5.61*x
Buffalo lone male
(d)
Woody species disturbance
y=0.54+-3.82*x
Buffalo breeding herd
(e)
R² Linear = 0.142
VCS
y=4.22E2+-7E2*x
Elephant bachelor herd
(f)

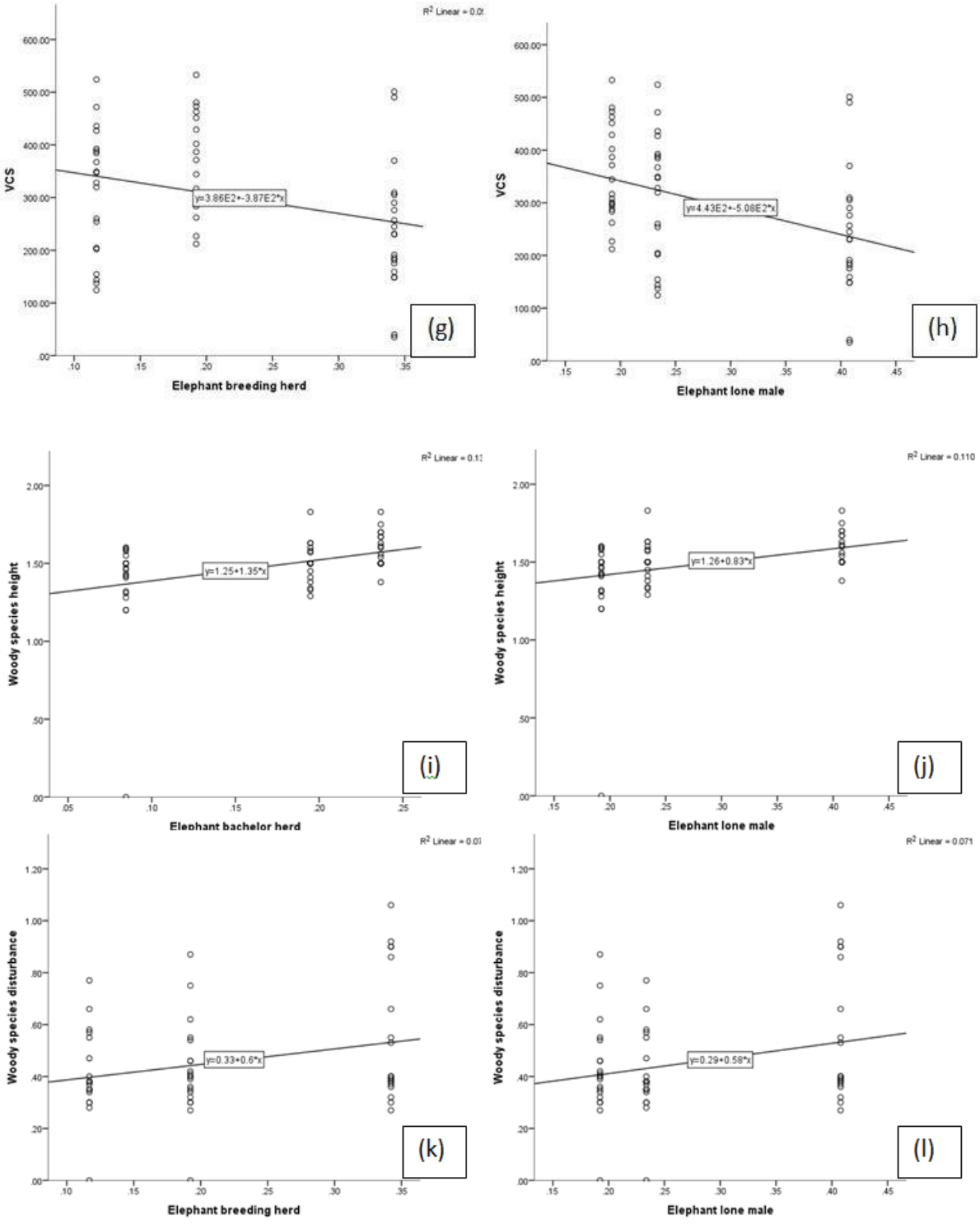


Figure 6.6: Nature of the relationships between: (a) VCS and number of buffalo breeding herds to visit earth dams, (b) VCS and number of buffalo lone males to visit earth dams, (c) Woody species height and number of buffalo breeding herds to visit earth dams, (d) Woody species height and number of buffalo lone males to visit earth dams, (e) Woody species disturbance and number of buffalo breeding herds to visit earth dams, (f) VCS and number of elephant bachelor herds to visit earth dams, (g) VCS and number of elephant breeding

herds to visit earth dams, (h) VCS and number of elephant lone males to visit earth dams, (i) woody species height and number of elephant bachelor herds to visit earth dams, (j) woody species height and number of elephant lone males to visit earth dams, (k) woody species disturbance and number of elephant breeding herds to visit earth dams, and (l) woody species disturbance and number of elephant lone males to visit earth dams.

Positive relationships were observed between VCS and numbers of buffalo breeding herds, and between woody species height and numbers of buffalo lone males, elephant bachelor herds and elephant lone males. Negative relationships were observed between VCS and numbers of buffalo lone males, elephant bachelor herds, elephant breeding herds and elephant lone males, between woody species height and buffalo breeding herds and between woody species disturbance and numbers of buffalo breeding herds.

6.4 Discussion

6.4.1 The influence of herbivores on habitat integrity

Veld condition score was found to be lower where numbers of kudu visiting waterholes were higher, and VCS was higher where numbers of zebra were lower. These results are unexpected, considering that kudu foraging strategies are associated with woody plant species (Redfern *et. al.* 2003; Smit *et. al.* 2007). In this study, kudu were generally associated with areas containing trees in the upper height class. Veld condition scores are typically higher below the canopies of larger trees (Treydte *et. al.* 2009) which suggests that if kudu utilise areas containing trees in the upper height class, that they would also, incidentally, select areas with high Veld Condition Scores. Despite this, kudu were significantly associated with areas of lower VCS, which is likely attributed to the competition that exists between the woody layer and the herbaceous layer (Joubert *et. al.* 2008). Being grazers, zebra are associated with areas of higher VCS (Redfern *et. al.* 2003; Smit *et. al.* 2007) and thus directly impact the herbaceous layer. I expect that zebra will be found in areas with higher VCS if the grazing capacity of the reserve is not being exceeded, since zebra select habitats based on

their foraging requirements (Ferrar & Walker 1974), and zebra in particular select resources high in nitrogen (Grange & Duncan 2006).

In addition to kudu, black rhino and waterbuck were also associated with greater woody species height. As browsers, black rhino and kudu may be expected to select areas with greater woody species height as taller trees have been found to have lower concentrations of herbivory defence mechanisms such as thorns, chemicals and polyphenols (Palo *et. al.* 1993). However, a greater woody species height may also mean that the browse is inaccessible to kudu and black rhino. As grazers, the association of waterbuck with areas of greater woody species height is more likely to be attributed to their preference for densely wooded areas (Melton 1978).

Black rhino were the only species associated with disturbance. Given the small population size of black rhino at the study site (n=5), it is unlikely that black rhino were a major contributor to elevated levels of disturbance. Black rhino distribution is a confounding variable when considering numbers of black rhino visiting waterholes and the disturbance at the waterholes they visit as black rhino were predominantly observed at earth dams which were associated with the highest levels of disturbance.

Browsers and grazers were associated with VCS and woody species height. Veld condition score was highest where the most browsers and grazers were observed. The association of browsers with high veld condition score is confounded by the presence of high quality grazing under large savannah trees (Treydte *et. al.* 2009) as browsers were also most prevalent in areas with greater woody species height. This selection may have been due to lower concentrations of herbivory defence mechanisms on taller trees as mentioned previously in this section (Palo *et. al.* 1993). The presence of higher numbers of grazers associated with greater VCS is a result of grazers selecting according to maximum forage availability (Ferrar & Walker 1974).

The only buffalo herd type to be significantly associated with any of the habitat integrity variables, was breeding herds. Buffalo breeding herds were positively associated with VCS and negatively associated with woody species diversity. Buffalo breeding herds are highly

mobile (Hay *et. al.* 2008) and travel long distances to meet their daily dietary requirements (Mwangi & Western 1998). It can therefore be expected that buffalo breeding herds select for areas with high veld condition scores. Buffalo breeding herds were also associated with woody species diversity; lower woody species diversity observed was associated with increased observations of buffalo breeding herds. This was expected, considering the unselective feeding habits of buffalo (Seydack *et. al.* 2012b), which results in buffalo consuming woody plant seedlings whilst grazing (Midgely *et. al.* 2010). High rates of seedling mortality reduces woody species diversity by preventing a wide range of woody species to establish. It has also been suggested that the increased trampling effect accompanying the presence of larger numbers of individuals associated with buffalo breeding herds (Hay *et. al.* 2008) results in the mortality of adult plants of certain woody species, and opening up areas for greater seedling recruitment (Hobbs & Huenneke 1992; Roques *et. al.* 2001).

Elephant bachelor herds were positively associated with woody species height and elephant breeding herds were positively associated with veld condition score. Male elephants are often associated with taller trees than females (Shannon *et. al.* 2006) and are found in areas with greater woody species height. In addition to this, male elephants have destructive feeding habits (Shannon *et. al.* 2006), and are more likely to uproot smaller woody plant species such as *Grewia* spp. Male elephants thus increase the average height of woody species by removing shorter individuals. Elephants are highly mobile (Verlinden & Gavor 1998) and elephant breeding herds select areas with higher grazing values (Ferrar & Walker 1974). Furthermore, elephant breeding herds prefer reservoirs, which have the highest VCS.

6.4.2 The influence of herbivores on habitat integrity for the different waterhole types

Collected data were separated according to waterhole type to determine whether there was an association between herbivore utilisation and habitat integrity for the different waterhole types. The only waterhole type at which herbivore utilisation was significantly correlated with habitat integrity, was earth dams. At earth dams, warthog were the only species not to be correlated with VCS. Combined data for all waterhole types showed that only kudu and zebra were significantly associated with VCS. The level of significance,

indicated by the *p*-value of the correlation, did not vary between the correlation test of numbers of kudu and VCS across the entire data set and numbers of kudu at earth dams. The level of significance between numbers of zebra and VCS was lower when earth dams were considered separately. Fewer herbivore species were correlated with the height of woody species when data from all waterhole types were included. When earth dams were considered separately, more herbivore species were correlated with the height of woody species. Numbers of buffalo, duiker, giraffe, impala, kudu, waterbuck, wildebeest, white rhino and zebra were all found to be significantly correlated to woody species height at earth dams compared to just black rhino and waterbuck when the whole data set was considered. Numbers of black rhino, duiker, elephant, impala and waterbuck were all significantly associated with disturbance at earth dams. When the entire data set was considered as a whole, the significance of correlations between numbers of duiker, elephant, impala and waterbuck and disturbance increased and the significance of correlations between numbers of black rhino and disturbance decreased.

All foraging strategies were significantly associated with VCS at earth dams, compared to just browsers and mixed feeders when the whole data set was analysed. Browsers were the only foraging category to be correlated with height when the whole data set was considered, however, when the waterhole types were separated, browsers, grazers and mixed feeders were correlated with height at earth dams. Overall, disturbance was not correlated with foraging strategy, however, at earth dams grazers and mixed feeders were correlated with disturbance.

Buffalo breeding herds were correlated with VCS when the whole data set was considered – the same was observed for earth dams. Buffalo breeding herds were correlated with height and disturbance at earth dams, but not when the entire data set was considered. In addition, buffalo breeding herds were not associated with diversity at earth dams, but were when data from all waterholes was analysed together. Lone males were significantly associated with VCS and height at earth dams, but not when all waterholes were analysed together. An increase in significance between herbivore utilisation and habitat integrity at earth dams when waterhole types were analysed separately suggests that the rest of the data set dilutes this significance when all waterholes are analysed together. Conversely, a

decrease in significance between herbivore utilisation and habitat integrity at earth dams when waterhole types were analysed separately suggests that these trends are observed across the study waterholes to some degree.

Elephant bachelor herds, breeding herds and lone males were correlated with VCS at earth dams; whereas only elephant breeding herds were correlated with VCS when the entire data set was considered. Bachelor herds and lone males were significantly associated with woody species height at earth dams. For all waterhole types combined, bachelor herds were significantly associated with woody species height and more so for earth dams. Elephant breeding herds and lone males were significantly associated with disturbance at earth dams, but when the whole data set was considered, there was no association between any elephant herd type and disturbance.

The increases in numbers of herbivore utilisation variables significantly associated with habitat integrity variables at earth dams could be attributed to the small sample size representation of different waterhole types (n=3 per waterhole type). However, the sample sizes were equal across the waterhole types so it is more likely that the impact of herbivores at earth dams is greater due to the higher numbers of herbivore visitations observed at earth dams. Lower levels of significance at earth dams are attributed to the relationship between herbivore utilisation and habitat integrity not being specific to a particular waterhole type

6.4.3 Conclusions

Results indicate that some herbivores had more significant associations than others to the various components of the vegetation surrounding waterholes including veld condition score, woody species diversity, woody species height and woody species disturbance. Since habitat score, which combined herbaceous and woody layer components, was not significantly correlated to utilisation by any single herbivore species, it is suggested that the impact of numbers of herbivores per species to visit a waterhole, numbers of herbivores from each of the foraging categories to visit a waterhole, and the effect of numbers of different herd types for buffalo and elephants on habitat integrity as a whole, was not

significant. These results are unexpected, as certain species have a particularly high level of impact on vegetation, for example, impala were not significantly related to habitat integrity when all the waterholes were analysed; however, they have been reported to have particularly high impact on vegetation elsewhere (Midgely *et. al.* 2010). Elephant are another species reported to have a high impact on vegetation (Midgely *et. al.* 2010), but numbers of individual elephants were not significantly correlated with habitat integrity. Breeding herds were associated with areas that had high VCS and bachelor herds with areas containing trees in the upper height class. Neither breeding or bachelor herds had a detrimental impact on habitat integrity. These results are in accordance with Kalwij *et. al.* (2010) who found that despite a growing elephant population in Chobe, woody layer biomass increased. Buffalo have also been found to be particularly detrimental to vegetation (Midgely *et. al.* 2010; Seydack *et. al.* 2010), but in this study were only negatively associated with woody species diversity.

While some significant associations were recorded, the data and extent of possible analyses were limited in terms of determining whether or not the results were a product of herbivores influencing their habitat, or whether certain habitat characteristics (like availability of high quality forage resources) were influencing herbivores (Ferrar & Walker 1976; Grange & Duncan 2006). Additional research into individual species habitat selection and dietary requirements at the study site are recommended to further explore the nature of relationships between herbivore utilisation and habitat integrity.

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Chapter 7 : Conclusions

7.1 Herbivore utilisation of waterholes

Camera trap data collected at waterholes to quantitatively establish patterns of herbivore utilisation, specifically the effect of artificial waterholes on habitat integrity, and the significance of waterhole design, showed that earth dams were the busiest waterhole type, utilised by the greatest diversity of species. Earth dams provided opportunities for herbivores to meet their cooling, wallowing and drinking requirements. Wallowing was limited at other waterhole types due to the concrete bases observed at pans, reservoirs and troughs. Reservoirs showed the least amount of utilisation and the lowest diversity of species, suggesting that reservoirs are least valuable in terms of meeting the requirements of herbivores.

7.2 Impact of artificial waterholes on habitat integrity

Vegetation surveys were carried out in a one kilometre radius of the different waterhole types to determine whether variation in habitat integrity was:

a. related to distance from waterholes
b. related to differences between the waterhole types.

This was done to determine if distance from artificial waterholes influenced habitat integrity and establish if this influence depended on the type of waterhole.

There were significant relationships between distance from waterholes and various components of habitat integrity including veld condition score (VCS), height of woody species and disturbance. The findings of this study suggest that artificial waterholes have an impact on habitat integrity in the study area with reduced habitat integrity observed closer to waterholes. With this in mind, significant relationships were most often associated with earth dams, suggesting that earth dams have the greatest level of impact on habitat

integrity. In addition to this, there were significant relationships between waterhole types and VCS, mean height of woody species and level of disturbance. Lowest VCS and highest disturbance levels were associated with earth dams, strengthening the suggestion that the greatest impact on habitat integrity was associated with earth dams. The highest VCS and the lowest disturbance levels within the reserve were associated with reservoirs.

7.3 Assessing the influence of waterhole design on habitat integrity with reference to specific herbivores

Data collected on herbivore utilisation at waterholes and habitat integrity surrounding waterholes were correlated to determine if specific herbivore utilisation could be related to habitat integrity. Further analysis were carried out to determine if these relationships varied between waterhole type to establish which waterhole types had the greatest influence on habitat integrity.

Herbivore utilisation was significantly related to VCS, height of woody species and disturbance to woody plant species, foraging categories and herd types. When these correlations were evaluated for the different waterhole types, all significant correlations were observed for earth dams. Earth dams had the greatest level of utilisation, the lowest mean VCS and highest disturbance to woody plant species. For reservoirs, herbivore utilisation was lowest, VCS was highest, and disturbance lowest. As elephants were the most frequent visitors to reservoirs, these results were unexpected based on literature suggesting the significant and negative impact elephants have on vegetation (Shannon *et. al.* 2006; O'Connor *et. al.* 2007; Midgely *et. al.* 2010). This study therefore suggests that the impact of elephants alone is not responsible for vegetation decline, but rather the accumulative impact of many herbivores.

7.4 Conservation implications and management recommendations

The provision of artificial water sources in nature reserves has been reported to be detrimental to surrounding vegetation (Thrash *et. al.* 1995; Thrash 2000; Smit *et. al.* 2007). This study found that VCS, woody species height and woody species disturbance were related to distance from waterholes, and waterhole type/design. Waterhole type influences the level of impact that a waterhole has on surrounding vegetation, with earth dams having the greatest impact. Given the importance of earth dams in terms of herbivore utilisation, and given the high frequencies of utilisation (particularly wallowing), it is recommended that earth dams remain open. Given the low impact observed at pans and reservoirs, it is not recommended that these waterholes be closed as their presence mitigates the impact of herbivores at earth dams by providing alternative water sources. According to Owen-Smith (1996), stocking rates influence the impact of herbivores on vegetation surrounding waterholes. It is therefore suggested that continued monitoring of vegetation surrounding waterholes be carried out while proactively monitoring and managing herbivore stocking rates as increased population sizes lead to increased impact. Particular emphasis should be placed on grazing species because VCS and overall habitat integrity are correlated with herbivore utilisation.

Management of artificial water sources has been shown to be an effective management tool for controlling the impact of elephants on the landscape (Chamaillé-Jammes *et. al.* 2007). This study did not find a negative relationship between elephants and habitat integrity indicating that the manipulation of artificial water sources is not necessary to control the impact of elephants.

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